

Experimental and Semiclassical Stark Widths and Shifts for Spectral Lines of Neutral and Ionized Atoms **(A Critical Review of Experimental and Semiclassical Data for the Period 2008 through 2020)**

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This review article presents the comparison of new experimental and corresponding semiclassical Stark-broadened data for non-hydrogenic spectral lines of neutral atoms and positive ions. The review covers the period 2008 until the end of 2020 and presents the continuation of previous critical reviews from 1976 (two), 1984 (two), 1990, 2002, and one from 2009. This review reports the Stark parameters of 1665 spectral lines belonging to the 35 elements with 61 different atomic and ion species. The data are taken from 59 papers. Experimental data are arranged in accordance with elements and spectra, and these are reported in tables in alphabetical and numerical order, respectively. Each experimental Stark broadening parameter is followed with estimated accuracy. The experimental Stark broadening and shift data presented in the tables are compared with corresponding semiclassical results in the literature. In addition, for comparison experiments versus semiclassical theoretical Stark parameters, a numerically improved theoretical approach developed based on Griem and co-workers' theory is used to evaluate Stark widths and shifts of all studied lines whenever required atomic energy levels data and transition probabilities are available. At the end of the text report, for each

analyzed neutral or ion specie, the information about the same species data and the location in preceding reviews is given.

Keywords: critically evaluated data; full width at half maximum intensity; neutral atoms; positive ions; Stark broadening parameters; Stark shifts; Stark widths.

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1. Introduction

This is a continuation of a series of critical review papers on experimental Stark broadening data for atoms and ions.¹⁻⁷ This review covers the results of experimental Stark broadening data from 2008 to the 2020 year. At the end of the text report, information is given for each element about previous Critical Review (CR) papers¹⁻⁷, where one can find earlier published data about the same element. In some cases, there are no previous Stark broadening data. In a few cases⁸⁻¹¹, for the Al, Mn, and Sn elements are reported the data published in the papers from 2007, which are omitted in the preceding review.⁷

The reports are given in a separate section for each element, in alphabetical order, according to the element's name. Each section contains (i) Ground state and Ionization energy data for the studied element, (ii) a short description of the experiments, (iii) necessary Reference data, (iv) a Finding list, (v) Key data on experiments and (vi) the table of Numerical results. Comparisons of experimental results with corresponding calculated data based on semiclassical theory are made whenever enough large sets of atomic parameters necessary for calculations are available and when the theoretical results from other authors are available.

Detailed comments about plasma sources, some plasma properties such as inhomogeneity, plasma diagnostics, and description of effects affecting the shape and shift of spectral lines are given in detail in earlier critical review papers.^{1,2,4}

2. Arrangement of the Tables

The order of the data in the tables of Numerical results is organized by multiplets. The wavelengths of spectral lines, transitions, and multiplets are given according to the notation presented in the NIST Database¹². The same is for the order of multiplets in the tables of Numerical results. The ground state and ionization energy data are also taken from NIST Database. In several cases where there is no data in the NIST Database, the sources of the displayed data are mentioned. The data are followed by two columns with plasma parameters, electron temperature, and electron density. The electron densities always are given in units of 10^{17} cm^{-3} . The next column contains experimental Stark halfwidth data, w_m , in Å units. The full widths measured at half maximum spectral line intensity (FWHM), are always reported.

After the halfwidth experimental data, the comparison with theoretical results, w_m/w_{th} , is given. In the same order are organized the shift data, d_m , and comparison, d_m/d_{th} , with theoretical results. Most of the Stark shifts are measured with respect to the spectral line maximum wavelength position. In several cases when shift refers to the halfwidth position this is noted. In the shift case, there are two possibilities positive shift (+) when the spectral line emitted from the plasma is shifted toward longer wavelengths (red shift) and the opposite is negative (-) blue shift. In some cases, in d_m/d_{th} columns the +/- symbol appears which means that the experiment shows a positive shift while the theory predicts a negative shift. There is also an opposite, -/+, situation. After the results and comparison with the theory comes a column (Acc.) with the evaluation of measured halfwidths, the first letter, and shifts, the second letter. The last column contains reference notifications.

3. Comparisons with Theory

For the comparison of experimental and theoretical Stark parameters, the numerically improved semiclassical (SC) formalism for neutral and ion emitters, based on work by Griem and coworkers¹³⁻¹⁵ was used in this report.

The improvements are as follows:

1. Numerical integration is done for all plasma electron velocities rather than for the reduced domain of electron velocities, see Ref. 13.
2. The authors in this study use the newest atomic data from the NIST ASD¹⁶, which improves the semiclassical calculations of Stark parameters. Unfortunately, Griem's results¹³⁻¹⁵ use the atomic energy levels and transition probabilities from early '70, which occasionally suffer from an

incomplete set of energy levels and transition probabilities, misidentified energy levels, or possibly wrong manually introduced atomic data required by Griem's code.

3. Griem¹³⁻¹⁵ didn't confirm that his published data are calculated using either one or multi-electron summation rule, which ultimately depends on the complexity of an atomic structure of the investigated multiplet of emitter ion. However, the authors had to identify the applicability of the one or multi-electron summation rules for the investigated spectral lines emitted from different atomic ionization states and perform corresponding Stark parameter calculations.

The details about applied semiclassical calculations can be found in Refs. 17-19. All Stark parameter calculations are done with the software package developed in MATLAB by Blagojević.²⁰

The line strengths of transitions occurring between the perturbing energy levels and the energy levels of the observed transition of the emitter are either read from NIST ASD or computed by the software package used in this work. When the required line strengths are not published in NIST ASD, the software package will calculate them. The radial integral part of the line strength is computed by the Bates-Damgaard method²¹ by applying the Coulomb approximation with the radial function represented by Freidrich et al.²² and integrated numerically. The relative line and multiplet strengths for all reported transitions are calculated within the corresponding angular momentum coupling scheme, including LS, LK, J₁K, and J₁j. The software package also supports mixed-coupling schemes within the observed transition.²³

All calculated Stark parameters are averaged over the multiplet for evaluation and comparison with the published Stark parameter measurements. The software package computes the Stark parameters for one-electron transitions only. In the case of transitions with equivalent electrons, the coefficients of fractional parentage are calculated for corresponding *p*, *d*, and *f* orbitals.^{24,25} The accuracy of the semiclassical calculations in this report is estimated from the numerically computed value of the completeness of a set of perturbing energy levels $\Delta S/S$ ¹⁵ for each investigated transition:

$$\frac{\Delta S}{S} = \frac{\sum_{i \neq f} R_{ii}^2 + \sum_{f \neq i} R_{ff}^2 - (R_{ii}^2 + R_{ff}^2)}{R_{ii}^2 + R_{ff}^2}$$

where R_{if}^2 are matrix elements of the coordinate operators. Ideally, the completeness of a set of perturbing energy levels should be equal to zero.

To preserve the accuracy of semiclassical predictions in this report within $\pm 20\%$, the values of the computed completeness parameter are kept within the $-0.6 \leq \Delta S/S \leq 0.1$ ranges. This range was estimated based on Ref. 13, with the accuracy of input data sets taken from the NIST ASD and computed using Ref. 20.

In this study, the data from Griem¹³ and semiclassical results of numerous other authors, based on Refs. 26-32, are also used to compare experimental and theoretical Stark parameters of neutral and ion emitters of different elements. More information can be found in the Stark-B database.³³

4. Accuracy of the evaluation procedure

The accuracy of Stark widths and shifts evaluation is based on Taylor and Kuyatt recommendations³⁴ which may be applied in systems where several parameters are measured. Instead of linear summing up estimated errors used frequently earlier, the square root of the sum of the squares of each particular error is evaluated. In the measurements of Stark widths and shifts only two line shape parameters errors are dominant: Δw_m or Δd_m and in addition, electron density error, ΔN_e . These estimated errors are reported by the authors of the analyzed experiment. The rest of the errors may be neglected and the formulas for evaluation of accuracy look like:

$$\begin{aligned} accw(\%) &= \sqrt{\Delta w_m^2 + \Delta N_e^2} \\ accd(\%) &= \sqrt{\Delta d_m^2 + \Delta N_e^2} \end{aligned}$$

Up to the fifth critical review⁵ from 1990, the total errors, marked as Acc in the tables of Numerical results, were calculated as a sum of $\Delta w_m + \Delta N_e$ and similar for the shift $\Delta d_m + \Delta N_e$. Thus, when one compares Stark broadening parameters from these two periods with different accuracy evaluations, total error until the end of critical review⁵ should be recalculated in accordance with the above formulas.

To facilitate the comparison of accuracies between experiments, the letter code as in Ref. 6 is used:

A = uncertainties with 15%

B^+ = uncertainties with 23%
 B = uncertainties with 30%
 C^+ = uncertainties with 40%
 C = uncertainties with 50%
 D = uncertainties larger than 50%

Sometimes one can notice that the evaluated total accuracy of the Stark broadening data is not equivalent to the above letter code in the Numerical results table. This is usually the decrease of accuracy introduced by the authors of this review, which notice that something important is missing in an experiment or there is no adequate explanation in the analyses of the results. More details that affect increase the error and ruin overall accuracy can be found in Ref. 6 and Ref. 35.

5. Conclusions

In this critical review experimental Stark broadening data for isolated neutral and positive ion non-hydrogen spectral lines are presented and critically evaluated for the time period 2008_until the end of 2020. As in preceding reviews¹⁻⁷ experimental data are also compared with the literature available on semiclassical Stark broadening parameters. Apart from already existing theoretical data, the comparison is made with newly calculated Stark broadening parameters performed by the authors of this work. So, in this case, much more comparisons of experimental versus theoretical data are performed than in preceding critical reviews.¹⁻⁷ In addition, a number of experimental results for the Stark parameters of, Sb III, Ba I, Cd III, Au I, Pb IV, Pb V, Mo I, Mo II, Sn IV, Ti II, W I, U I, U II, V II and Zr II, which are not available in previous critical reviews¹⁻⁷, appeared in recent years and they are studied in this review. During the analysis of experiments for this study, one novelty in this field is noticed. In comparison with gas discharges previously almost exclusively used for light sources, now laser-induced plasma is more applied. For this application Nd:YAG lasers which emit first or second or fourth harmonics are used.

6. Acknowledgements

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8. Tables of Stark Widths and Shifts

Aluminum

Al I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^2 P^0_{1/2}$

Ionization energy: $5.985769 \text{ eV} = 48\,278.480 \text{ cm}^{-1}$

Sherbini *et al.*¹ studied line shapes of two resonance lines of Al I 3944.01 Å and 3961.52 Å using as a light source Laser Induced Plasma (LIP), see Table Key data on experiments. This study of Al I line shapes was carried out in Pisa and Cairo under optically thick conditions with the line shapes distorted by self-absorption effect. The authors¹ developed mathematical procedure based on known ratio of line intensities within multiplet 1 of Al I to determine Stark widths for optically thin conditions.

Although the authors claim that the results for Stark widths for both lines are for optically thin conditions, the comparison of w_m for both lines at the same temperature shows always larger Stark widths for the weaker line 3944.01 Å than for the stronger 3961.52 Å line (line strength ratio 1 : 2). This is unexpected if the self-absorption is the cause; it should be *vice versa*. Second, in accordance with comprehensive study² of Stark widths within multiplet in many cases Stark widths are almost the same within multiplet (most probably within 1% or even better). There are in some cases certain irregularities, but they can be explained with irregular disposition of perturbing energy levels. These irregularities are relatively rare and can't be applied in the case of studied Al I resonance lines. Therefore, another examination of Stark widths within multiplet 1 is needed.

The comparison of measured, w_m , Al I Stark halfwidths with three sets of corresponding theoretical values, two from Refs. 3 (G) and 4 (DSB) and

halfwidths calculated in this work (TW), is presented in three parallel columns. More Al I experimental data in earlier critical reviews, CR (1984, 90).

References

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Key data on experiments

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Experiment Pisa: Nd:YAG laser at 1064 nm Single pulse 160 mJ Double pulse 80 + 80 mJ, 12 ns per pulse width Experiment Cairo: Nd:YAG laser at 1064 nm Single pulse 800 mJ, 6 ns Target: pure aluminum in air	H $_{\alpha}$ Stark halfwidth	Saha-Boltzmann plot by using Al I and Al II lines	Both experiments: Plasma observed side-on No Abel inversion Resonance broadening not considered.

Numerical results for Al I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	Acc.	Ref.
1	3p – 4s	² P° – ² S	3944. 01	12760	1	0.28	0.82	0.96	0.78	C	1
				13000	1	0.27	0.79	0.93	0.74	C	1
				15550	1	0.27	0.76	0.90	0.70	C	1
				16250	1	0.25	0.69	0.83	0.64	C	1
			3961.5 2	12760	1	0.22	0.64	0.75	0.61	C	1
				13000	1	0.25	0.73	0.85	0.68	C	1
				15550	1	0.24	0.67	0.79	0.62	C	1
				16250	1	0.24	0.66	0.79	0.61	C	1
The average ratio values							0.72	0.85	0.67		

Aluminum

Al II

Ground state: $1s^2 2s^2 2p^6 3s^2 \ ^1S_0$

Ionization energy: $18.82855 \text{ eV} = 151\,862.5 \text{ cm}^{-1}$

The results of two Laser Induced Plasma (LIP) studies of Al II Stark broadening lines carried out for different conditions in laboratories located in Marseille and in Belgrade, are published in a single paper.¹ Other experimental Stark broadening results are given in Ref. 2. For details of these studies, see Key data on experiments, while all results, comparisons and estimated data uncertainties are in the table with Numerical results. Although the experiments, described in Ref. 1, were performed with three different target materials at two different initial gas pressures (low pressure argon and atmospheric pressure air) and with plasma generation using two considerably different laser wavelengths, 266 nm and 1064 nm, Stark widths of measured Al II lines show good consistency. All Al II plasma lines observations were carried out side-on and followed by Abel inversion. Here should be noted that the authors of Marseille experiment used for wavelength and transition probabilities source by Kurucz and Bell³ while in Belgrade NIST Database⁴ is applied.

In Ref. 2 Abel inversion procedure is applied and self-absorption test carried out.

The comparison with theoretical SC theoretical results calculated by Griem⁵ (G) and data evaluated within this work (TW).

CR (1976, 84, 90, 02).

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Finding list

Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.
2631.55	3	3586.56	5	5593.30	8	6830.29*	6
2816.19	1	4663.06	2	6237.55*	7	7049.35*	4

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	<p>Experiment Marseille: Nd:YAG laser at 266 nm Single pulse 40 mJ, 5 ns Target: copper-aluminum alloy, Argon pressure in the interaction chamber 5×10^3 Pa</p> <p>Experiment Belgrade: Nd:YAG laser at 1064 nm Single pulse 50 mJ, 15 ns Target: pellet and alumina Experiment performed at atmospheric pressure in air</p>	H_{α} Stark halfwidth	Boltzmann plot of Fe II, Mg I and Al II lines	Plasma observed side-on in both experiments
2	<p>Nd:YAG laser, EKSPLA NL311-SH-TH, 532 nm, 200 mJ, 5ns, repetition 1 Hz Target: aluminum sample (purity 99%) The experiment was conducted in helium-hydrogen gas mixture (92% He, 8% H) under pressure of 300mbar</p>	H_{β} Stark halfwidth	Boltzmann plot of six Al II and eight Al III spectral lines	Plasma observed side-on

Key data on experiments

Numerical results for Al II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron		w_m (Å)	w_m/w_G	w_m/w_{TW}	Acc.	Ref.
					density (10^{17} cm^{-3})						
1	$3p - 4s$	$^1P^o - ^1S$	2816.19	28000	1	0.4			1.90	B ⁺	2
2	$3p^2 - 4p$	$^1D - ^1P^o$	4663.06	28000	1	1.0			1.06	B ⁺	2
3	$3p^2 - 4f$	$^1D - ^1F^o$	2631.55	28000	1	0.6				B ⁺	2
4	$4s - 4p$	$^3S - ^3P^o$	7049.35 *	6300	1	2.1	1.07		1.28	B	1
				6400	1	2.1	1.07		1.29	B	1
				6400	1.1	2.1	0.97		1.17	B	1
				10500	2	3.4	0.99		1.20	C ⁺	1
				11900	2.2	3.4	0.92		1.12	C ⁺	1
				11900	2.3	3.5	0.91		1.11	C ⁺	1
				15800	1.4	2.1	0.93		1.15	B	1
				16200	1.5	2.3	0.96		1.18	B	1
				16700	1.6	2.3	0.90		1.12	B	1
				16700	1.7	2.5	0.92		1.14	B	1
				16900	1.7	2.5	0.96		1.19	B	1
5	$3d - 4f$	$^3D - ^3F^o$	3586.56	6300	1	1.6			1.48	C ⁺	1
				6400	1	1.6			1.49	C ⁺	1
				6400	1.1	1.7			1.44	C ⁺	1
				6800	0.9	1.6			1.68	C ⁺	1
				10500	2	2.5			1.34	C ⁺	1
				11900	2.2	2.6			1.31	C ⁺	1
				11900	2.3	2.6			1.25	C ⁺	1
				16200	1.5	1.9			1.50	C ⁺	1
				16700	1.6	1.7			1.27	C ⁺	1
				16700	1.7	1.7			1.19	C ⁺	1
				16900	1.7	1.6			1.13	C ⁺	1
				28000	1	1.2			0.84	B ⁺	2
						9					
6	$4p - 5s$	$^3P^o - ^3S$	6830.29 *	10500	2	7.0	1.00		0.98	C ⁺	1
				11900	2.2	7.2	0.95		0.93	C ⁺	1
7	$4p - 4d$	$^3P^o - ^3D$	6237.55 *	10500	2	7.4	0.95		0.97	C ⁺	1
				11900	2.2	7.4	0.92		0.91	C ⁺	1

*The wavelengths, in Ref. 1, are given as average wavelengths for the multiplets

Aluminum

Al III

Ground state: $1s^2 2s^2 2p^6 3s^2 S_{1/2}$

Ionization energy: $28.447642 \text{ eV} = 229\,445.71 \text{ cm}^{-1}$

Nd:YAG laser, induced plasma is used for measurement of Stark broadening halfwidths of eight Al III spectral lines. Plasma observations are carried out side-on, Abel inversion procedure performed, self-absorption tested to determine optically thin conditions, which are used for determination of Al III Stark broadened halfwidths. All details of experimental equipment, and plasma diagnostics one can find in Key data on experiments.

Semiclassical evaluations of Stark broadening halfwidths are performed within theory² (DSB) and this work (TW). The results of measured and compared with semiclassical halfwidths, as well as average ratios of measured over theoretical values one can find in the table of Numerical results for Al III.

CR (2002).

References

¹D. Dojić, M. Skočić, S. Bukvić, S. Djeniže, Spectrochim. Acta B **166**, 105816 (2020).

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Finding list

Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.
3601.63	1	3702.11	4	4512.56	3	5696.60	2
3612.36	1	3713.12	4	4529.19	3	5722.73	2

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser, EKSPLA NL311-SH-TH, at 532 nm, 200 mJ, 5ns, repetition 1 Hz Target: aluminum sample (purity 99%) The experiment was conducted in helium-hydrogen gas mixture (92% He, 8% H ₂) under pressure of 300 mbar	H _β Stark halfwidth	Boltzmann plot of six Al II and eight Al III spectral lines	Plasma observed side-on

Numerical results for Al III

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m /w _{DSB}	w _m /w _{TW}	Acc.	Ref.
1	3 <i>d</i> - 4 <i>p</i>	² D - ² P ^o	3601.63	28000	1	0.38	1.21	1.13	B ⁺	1
		² S -	3612.36	28000	1	0.35	1.11	1.04	B ⁺	1
2	4 <i>s</i> - 4 <i>p</i>	² P ^o	5696.60	28000	1	1.00	0.98	1.04	A	1
			5722.73	28000	1	0.93	0.90	1.08	A	1
3	4 <i>p</i> - 4 <i>d</i>	² P ^o - ² D	4512.56	28000	1	1.21	1.10	0.95	B ⁺	1
			4529.19	28000	1	1.34	1.21	1.04	B ⁺	1
4	4 <i>p</i> - 5 <i>s</i>	² P ^o - ² S	3702.11	28000	1	1.11	1.59	1.25	B ⁺	1
			3713.12	28000	1	1.17	1.67	1.31	A	1
The average ratio values							1.22	1.11		

Antimony

Sb III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2 P^{\circ}_{1/2}$

Ionization energy: 25.3235 eV = 204 248 cm⁻¹

Plasma source used for recording and measurement of Stark broadening parameters of Sb III spectral lines is linear pulsed arc applied for the same purpose with several other elements and their ions, see e.g. the Reports for Si I up to Si IV. Different is usually only technique of introduction of studied species in discharge. In this experiment, as always as with other species, the self-absorption test is applied to studied Sb III lines. Only halfwidths of optically thin lines are used for derivation of Stark broadening parameter. The comparison with experiment we use SC calculations from this work (TW), see table of Numerical results for Sb III. In case of multiplet M6, where $\Delta S/S < -0.7$, comparison with calculated Stark parameters are not reported.

Comments: The notation of transitions, multiplets and wavelengths in Ref. 1 are taken from Ref. 2. There are no corresponding details about multiplets and transitions in NIST data base.³ In this work, NIST energy level tables are used to determine transitions in Numerical results for Sb III.

References

¹S. Djeniže, Phys. Lett. A **372**, 6658 (2008).

²R. J. Lang, Phys. Rev. **35**, 445 (1930).

³NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.
2669.39	3	3566.25	6	4352.16	1		
3504.07	5	3738.90	4	4591.89	2		
3559.18	6	4265.09	2	4692.91	1		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure arc The antimony atoms are sputtered from deposition of antimony on the thin cylindrical silver plates located in the homogenous part of the discharge. Discharge gas is 90% He + 7% N ₂ + 3% O ₂ at the pressure of 1330 Pa	Stark width of the He II P _α 4686 Å spectral line	Intensity ratio between O II (3954.4 Å and 3973.3 Å) and O III 3961.6 Å spectral lines	Plasma observed axially end-on

Numerical results for Sb III

No .	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m / w _{TW}	Acc .	Ref .
1	6 <i>s</i> - 6 <i>p</i>	² S - ² P ^o	4352.16	17500	0.94	0.26	0.50	B ⁺	1
			4692.91	17500	0.94	8	0.56	B ⁺	1
						0.32			
2	5 <i>p</i> ² - 6 <i>p</i>	² P - ² P ^o		17500	0.94	0.26	0.57	B ⁺	1
			4265.09	17500	0.94	2	0.55	B ⁺	1
			4591.89			0.29			
3	5 <i>d</i> - 4 <i>f</i>	² D - ² F ^o		17500	0.94	0.08	0.45	B ⁺	1
			2669.39			0			
						0			
4	6 <i>p</i> - 7 <i>s</i>	² P ^o - ² S		17500	0.94	0.22	0.59	B ⁺	1
			3738.90			5			
						0			
5	6 <i>p</i> - 6 <i>d</i>	² P ^o - ² D		17500	0.94	0.24	0.60	B ⁺	1
			3504.07			7			
						0			
6	4 <i>f</i> - 5 <i>g</i>	² F ^o - ² G		17500	0.94	0.23		B ⁺	1
				17500	0.94	2		B ⁺	1
			3559.18			0.22			
			3566.25			0			
The average ratio values							0.55		

Argon

Ar I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 \ ^1S_0$

Ionization energy: $15.7596119 \text{ eV} = 127\,109.842 \text{ cm}^{-1}$

Djurović *et al*¹ and Dzierzega *et al*² measured in each experiment Stark broadening parameters for a single Ar I line; one belonging to $4s - 5p$ and the other to $4s - 4p$ transition, respectively. First experiment is carried out in discharge with argon having small admixture of molecular hydrogen and in the latter case² laser induced plasma at sub atmospheric pressure of argon is used as a plasma source. All spectroscopic measurements in pulsed discharge were carried end-on. For plasma diagnostics the Balmer beta line and intensities of Ar II lines are used. For plasma diagnostics of second experiment Thomson scattering is applied, while for all_side-on radiation measurements Abel inversion procedure is applied. The results for the second experiment² are reported in the large range of electron temperatures starting from 10430 K up to 73400 K.

The comparison with SC calculations: for the line 6965.43 Å Ref 4 (D) is used while for 4259.36 Å Refs. 3 (G) and 5 (D) are applied. The calculations used in this work are applied for the both lines (TW). More Ar I experimental data in earlier critical reviews CR (1976, 84, 90, 02, 09).

References

- ¹S. Djurović, Z. Mijatović, R. Kobilarov, I. Savić, Plasma Sources Sci. Technol. **21**, 025007 9pp (2012).
- ²K. Dzierzega, W. Zawadzki, F. Sobczuk, M. L. Sankhe, S. Pellerin, M. Wartel, W. Olchawa, A. Baćławski, A. Bartecka, J. Quant. Spectrosc. Radiat. Transf. **237**, 106635 8pp (2019).
- ³H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
- ⁴M. S. Dimitrijević, M. Christova, S. Sahal-Bréchet, Phys. Scripta **75**, 809 (2007).
- ⁵M. S. Dimitrijević, A. Kovačević, Z. Simić, S. Sahal-Bréchet, Balt. Astron. **20**, 576 (2011).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Pulsed atmospheric pressure wall stabilized arc, operated in argon. Gas mixture with molecular hydrogen (97% Ar + 3% H ₂) introduced in central part of the arc, current pulse 210 A	H _β Stark halfwidth	Boltzmann plot of Ar II lines	Plasma observed end-on
2	Plasma induced in argon at 400 mbar by Nd:YAG laser 15 mJ with 4.5 ns pulse width at 532 nm with repetition rate of 10 Hz	Thomson scattering	Thomson scattering	Plasma observed side-on

Numerical results for Ar I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m / w _G	w _m /w _D	w _m / w _{TW}	Acc.	Ref.
1	4 <i>s</i> - 4 <i>p</i>	[3/2] ^o - [1/2]	6965.43	10430	0.28	0.17		0.68	0.73	C ⁺	2
				11670	0.47	0.28		0.65	0.69	B	2
				13415	0.66	0.39		0.62	0.65	B ⁺	2
				16250	0.94	0.70		0.75	0.77	B	2
				18550	1.28	1.02		0.77	0.80	B ⁺	2
				21010	1.66	1.37		0.77	0.80	B ⁺	2
				21240	1.27	1.08		0.79	0.82	B ⁺	2
				27680	2.13	1.99		0.80	0.85	B ⁺	2
				38200	2.83	2.77		0.76	0.84	B ⁺	2
				57400	3.67	4.92		0.90	1.06	B ⁺	2
				73400	5.69	6.13		0.68	0.80	B ⁺	2
The average ratio values								0.74*	0.80		
										*	
2	4 <i>s</i> - 5 <i>p</i>	[1/2] ^o - [1/2]	4259.36	13500	1.30	3.35	0.83	1.33*	0.78	B	1
										*	

* The average values for w_m/w_D in multiplet 1. ** Ion broadening is unavailable. Electron impact broadening only.

Argon

Ar II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^5 \ ^2P^o_{3/2}$

Ionization energy: 27.62967 eV = 222 848.3 cm⁻¹

Newly reported Stark broadening parameters are results of three experimental studies carried out in linear gas discharges.¹⁻³ The plasma source for the first two experiments were pulsed, wall stabilized atmospheric pressure arcs running in argon with small admixture of molecular hydrogen. The third plasma source³ is a low pressure pulsed argon arc. Plasma observations for all three experiments were performed axially end-on by means of mirrors and spectrometers equipped with CCD radiation detector with corresponding electronics for signal averaging and data analysis. In all experiments the width and shape of instrumental profile is reported and the presence of self-absorption of studied lines always checked and, if necessary, the line shape corrected to optically thin conditions before Stark broadening parameter measured. More details of the experiments are reported in the table “Key data on experiments”.

It is important to note that instead of expected close values for Stark halfwidths and shifts within multiplet (see the results of comprehensive studies^{4,5}), large variations of Stark parameters for several Ar II UV lines within multiplet 11 are detected in Ref 3, see table Numerical results for Ar II. The authors³ offered the explanation for this “irregularity” based on the irregular disposition of perturbing energy levels, see Fig. 3 in Ref. 3.

The SC theoretical data for halfwidths show remarkable average agreement with experiments (the average ratio measured/theoretical close to one, see last line of Numerical data table for Ar II). In cases of Ref. 6 (H) and this work (TW) certain ratios of measured over theoretical data are much larger or much smaller than one, but the average value remains close to one. To test this statement, we excluded ratios for multiplets 3, 11, 37, 47, 49, 50, 54, 56, 58 from evaluation of TW average ratio and instead of 1.00 we obtained 0.94. Similar test with data from Ref. 6 gave instead of 0.89 the average ratio 0.88. In the case of theory in Ref. 7 (G), the number of theoretical data is small for such kind analysis. It also should be noticed that the w_m/w_{TW} ratio, for multiplets M43 and M62 is not given because the $\Delta S/S$ is out of limits, see theory description in general introduction._

Although the Stark shifts are calculated in this work the scatter of ratio measured over theoretical results prevented any detailed analysis. The origin of this scatter is most likely related to the difficulties in small shift measurement.

Comment: The list of Stark broadening parameters for Ar II lines, which would include all experimental Ar II data published in earlier reviews, represents, up to now, the largest set of results for a singly charged ions. Present report extends this list with another 139 results for Ar II lines.

CR (1976, 84, 90, 02, 09).

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- ⁴W. L. Wiese, N. Konjević N., J. Quant. Spectrosc. Radiat. Transfer, **28**, 185 (1982).
- ⁵W. L. Wiese, N. Konjević, J. Quant. Spectrosc. Radiat. Transfer, **47**, 185 (1992).
- ⁶R. Hamdi, N. B. Nessib, S. Sahal-Bréchet, M. S. Dimitrijević, MNRAS **475**, 800 (2018).
- ⁷H. R. Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2647.84	54	3249.80	22	3660.44	49	3925.72	45
2744.79	53	3263.57	21	3669.60	17	3926.05	45
2757.30	52	3273.32	34	3671.00	49	3928.62	7
2764.65	39	3281.70	22	3678.27	17	3932.55	41
2844.13	12	3307.23	37	3680.06	50	3944.27	1
2865.84	30	3350.92	48	3718.21	57	3946.10	45
2891.61	11	3365.52	48	3720.43	17	3952.73	40
2924.63	59	3366.58	37	3729.31	7	3958.38	31
2931.48	60	3370.91	28	3737.89	57	3968.36	1
2932.59	12	3376.44	48	3754.05	49	3974.48	6
2942.89	11	3397.90	29	3763.50	25	3974.76	5
2955.39	35	3408.61	61	3765.27	17	3988.16	31
2960.24	59	3414.46	47	3770.52	17	4005.36	62
2979.05	11	3421.61	28	3780.84	25	4011.21	24
3014.48	35	3430.42	29	3786.38	2	4013.86	1
3026.75	51	3454.09	19	3796.59	56	4031.38	31
3028.91	38	3464.13	33	3799.38	25	4033.81	23
3033.51	11	3476.75	19	3803.17	56	4035.46	16
3046.08	44	3478.23	20	3808.57	2	4038.80	1
3066.89	44	3499.48	3	3809.46	17	4042.89	16
3082.98	51	3509.78	19	3819.02	55	4047.48	32
3093.40	38	3514.39	19	3825.67	55	4579.35	10
3139.02	22	3519.99	27	3826.81	25	4609.57	15

3161.37	42	3521.56	58	3830.52	55	4657.90	9
3165.29	43	3521.98	20	3841.52	25	4726.87	8
3169.67	22	3535.32	19	3844.73	25	4735.91	4
3181.04	22	3545.60	33	3845.40	6	4764.86	9
3186.17	43	3548.51	27	3850.58	7	4806.02	4
3194.23	21	3561.03	46	3856.14	26	4847.81	4
3204.32	34	3605.88	14	3868.53	41	4879.86	8
3212.52	22	3622.14	17	3875.26	1	4933.21	4
3221.63	21	3634.81	13	3880.33	25	4965.08	8
3225.97	21	3639.83	50	3900.63	25	5009.33	4
3236.81	37	3650.89	18	3911.58	25	5062.04	4
3243.69	22	3655.28	36	3914.77	1		

Key data on experiments

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Pulsed wall stabilized arc, operated in argon at atmospheric pressure Gas mixture of 97% Ar + 3% H ₂ introduced in the central part of the arc Current pulse 210 A	H _β Stark halfwidth	Boltzmann plot of Ar II lines	Plasma observed end-on
2	Pulsed wall stabilized arc, operated in argon at atmospheric pressure Gas mixture of 97% Ar + 3% H ₂ introduced in the central part of the arc Current pulses 210 A and 270 A	H _β Stark halfwidth	Boltzmann plot of Ar II lines	Plasma observed end-on
3	Low-pressure pulsed arc in argon (0.5 kPa)	Two wavelength interferometry	Boltzmann plot of Ar II lines	Plasma observed end-on

Numerical results for Ar II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_G	w_m/w_H	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{TW}	Acc.	Ref.
1	3d - 4p	⁴ D - ⁴ D°	3875.26	22000	1	0.176	0.93		0.85				C ⁺	3
			3914.77	22000	1	0.184	0.95		0.88	< 0.025		-----	C ⁺	3
			3944.27	22000	1	0.233	1.19		1.10	< 0.025		-----	B ⁺	3
			3968.36	22000	1	0.204	1.03		0.95	< 0.025		-----	C ⁺	3

			4013.86	22000	1	0.233	1.14		1.05	< 0.025	-----	C ⁺	3	
			4038.80	22000	1	0.241	1.17		1.09	0.031	0.42	D,	3	
												C ⁺		
2	3 <i>d</i> - 4 <i>p</i>	⁴ D - ² D ^o	3786.38	22000	1	0.235			1.05			B ⁺	3	
			3808.57	22000	1	0.225			1.00	0.048	+/-	D,	3	
												C ⁺		
3	3 <i>d</i> - 4 <i>p</i>	⁴ D - ⁴ S ^o	3499.48	22000	1	0.290			1.57			D	3	
4	4 <i>s</i> - 4 <i>p</i>	⁴ P - ⁴ P ^o	4735.91	13500	1.3	0.344	0.71		0.72			B ⁺	1	
				13400	1.3	0.39	0.80	0.59	0.81			B ⁺	2	
				14200	1.6	0.50	0.85	0.63	0.86			B ⁺	2	
			4806.02	13500	1.3	0.361	0.72		0.70			B ⁺	1	
				13400	1.3	0.40	0.80	0.59	0.77	- 0.15	1.62	0.77	B ⁺ ,	2
												D		
				14200	1.6	0.50	0.82	0.62	0.80	- 0.17	1.68	0.73	B ⁺ ,	2
												D		
			4847.81	13500	1.3	0.366	0.72		0.72			B ⁺	1	
				13400	1.3	0.45	0.88	0.64	0.88	- 0.23	2.44	1.32	B ⁺ ,	2
												D		
				14200	1.6	0.56	0.90	0.75	0.90			B ⁺	2	
			4933.21	13400	1.3	0.50	0.94	0.67	0.97			B ⁺	2	
				14200	1.6	0.55	0.86	0.61	0.88			B ⁺	2	
			5009.33	13400	1.3	0.54	0.99	0.71	1.01			B ⁺	2	
				14200	1.6	0.61	0.92	0.67	0.94	- 0.14	1.28	0.66	B ⁺ ,	2
												D		
			5062.04	13400	1.3	0.55	0.99	0.70	0.97			B ⁺	2	
				14200	1.6	0.63	0.93	0.67	0.92	- 0.13	1.16	0.53	B ⁺ ,	2
												D		
5	4 <i>s</i> - 4 <i>p</i>	⁴ P - ² D ^o	3974.76	22000	1	0.229		0.65	0.79	- 0.069		0.56	D, D	3
6	4 <i>s</i> - 4 <i>p</i>	⁴ P - ² P ^o	3845.40	22000	1	0.215		0.70	0.82	- 0.060		0.49	C ⁺ ,	3

			3974.48	22000	1	0.224	0.66	0.77	- 0.062	0.50	D C ⁺ ,	3
7	4s - 4p	⁴ P - ⁴ S ^o	3729.31	22000	1	0.166	0.59	0.71	- 0.070	1.04	D D,	3
			3850.58	22000	1	0.171	0.57	0.68	- 0.059	0.78	C ⁺ D, D	3
			3928.62	22000	1	0.178	0.56	0.67	- 0.068	0.84	D,	3
8	4s - 4p	² P - ² D ^o	4726.87	13500	1.3	0.405		0.74			C ⁺ B ⁺	1
				13400	1.3	0.55	0.70	1.01			B ⁺	2
				14200	1.6	0.63	0.67	0.95	- 0.14	0.57	B ⁺ ,	2
			4879.86	13500	1.3	0.459		0.80			D B ⁺	1
				13400	1.3	0.56	0.71	0.90	- 0.12	0.46	B ⁺ ,	2
				14200	1.6	0.70	0.73	0.93			D B ⁺	2
			4965.08	13400	1.3	0.60	0.70	0.96			B ⁺	2
				14200	1.6	0.71	0.69	0.93			B ⁺	2
9	4s - 4p	² P - ² P ^o	4657.90	13400	1.3	0.49	0.70	0.92	- 0.15	0.62	B ⁺ ,	2
				14200	1.6	0.58	0.69	0.90	- 0.16	0.55	D B ⁺ ,	2
			4764.86	13400	1.3	0.58	0.80	0.95			D B ⁺	2
				14200	1.6	0.64	0.72	0.88			B ⁺	2
10	4s - 4p	² P - ² S ^o	4579.35	13400	1.3	0.47	0.69	0.75			B ⁺	2
				14200	1.6	0.53	0.65	0.69			B ⁺	2
11	4s - 4p	² P - ² P ^o	2891.61	22000	1	0.542	1.72	1.74	0.225	3.07	B ⁺ B ⁺ ,	3
			2942.89	22000	1	0.335	1.14	1.29	0.040	0.60	C ⁺ ,	3
			2979.05	22000	1	0.592	1.76	1.78	0.228	3.02	D B ⁺ ,	3

			3033.51	22000	1	0.352		1.12	1.27	0.056		0.80	B ⁺ B ⁺ , C ⁺	3
12	4s - 4p	² P - ² D ^o	2844.13	22000	1	0.167		0.71	0.84	- 0.047		0.73	D, D	3
			2932.59	22000	1	0.207		0.84	0.97	- 0.078		1.10	D,	3
13	3d - 4p	² P - ² P ^o	3634.81	22000	1	0.491		1.22	1.22	0.222		1.56	C ⁺ D, D	3
14	3d - 4p	² P - ² D ^o	3605.88	22000	1	0.255		0.86	0.90	< 0.025		-----	C ⁺	3
15	4s - 4p	² D - ² F ^o	4609.57	13400	1.3	0.56		0.74	1.13				B ⁺	2
				14200	1.6	0.62		0.68	1.03				B ⁺	2
16	4s - 4p	² D - ² D ^o	4035.46	22000	1	0.317		0.80	0.87	- 0.048		0.56	C ⁺ , C ⁺	3
			4042.89	22000	1	0.293		0.68	0.79	- 0.043		0.47	D,	3
17	4p - 5s	⁴ P ^o - ⁴ P	3622.14	22000	1	0.684	1.11	1.17	1.01	0.360	1.12	1.00	C ⁺ B ⁺ , B ⁺	3
			3669.60	22000	1	0.627	0.99	1.05	0.91	0.290	0.88	0.79	C ⁺ , C ⁺	3
			3678.27	22000	1	0.671	1.06	1.12	1.02	0.270	0.82	0.77	C ⁺ , C ⁺	3
			3720.43	22000	1	0.638	0.98	1.04	0.95	0.257	0.76	0.72	D,	3
			3765.27	22000	1	0.626	0.94	1.01	0.96	0.253	0.73	0.75	B ⁺ C ⁺ , C ⁺	3
			3770.52	22000	1	0.686	1.03	1.09	1.00	0.264	0.76	0.74	C ⁺ , B ⁺	3
			3809.46	22000	1	0.687	1.01	1.08	1.03	0.351	0.99	1.00	B ⁺ , B ⁺	3
18	4p - 5s	⁴ P ^o - ² P	3650.89	22000	1	0.695		1.20	1.06	0.392		1.13	B ⁺ , B ⁺	3

			3249.80	22000	1	0.485	1.01	0.96	0.66	0.182	0.72	0.53	C ⁺ , B ⁺	3
			3281.70	22000	1	0.513	1.04	0.97	0.76	0.259	1.01	0.81	B ⁺ , B ⁺	3
23	4 <i>p</i> – 5 <i>s</i>	⁴ D° – ⁴ P	4033.81	22000	1	0.898		1.21	1.08	0.334		0.76	C ⁺ , B ⁺	3
24	4 <i>p</i> – 5 <i>s</i>	⁴ D° – ² P	4011.21	22000	1	0.822		1.17	1.05	0.360		0.86	C ⁺ , D	3
25	4 <i>p</i> – 4 <i>d</i>	⁴ D° – ⁴ D	3763.50	22000	1	0.552	1.01	0.94	1.00	0.164	0.57	0.69	B ⁺ , C ⁺	3
			3780.84	22000	1	0.511	0.93	0.85	0.92	0.178	0.62	0.76	C ⁺ , B ⁺	3
			3799.38	22000	1	0.550	0.99	0.89	0.98	0.215	0.74	0.90	B ⁺ , B ⁺	3
			3826.81	22000	1	0.538	0.96	0.88	0.95	0.201	0.68	0.83	B ⁺ , B ⁺	3
			3841.52	22000	1	0.482	0.85	0.77	0.84	0.201	0.68	0.83	B ⁺ , C ⁺	3
			3844.73	22000	1	0.591	1.04	0.96	1.04	0.206	0.69	0.85	C ⁺ , C ⁺	3
			3880.33	22000	1	0.504	0.87	0.78	0.87	0.290	0.96	1.18	C ⁺ , C ⁺	3
			3900.63	22000	1	0.555	0.95	0.88	0.94	0.213	0.69	0.86	C ⁺ , C ⁺	3
			3911.58	22000	1	0.514	0.87	0.79	0.87	0.241	0.78	0.96	B ⁺ , B ⁺	3
26	4 <i>p</i> – 3 <i>d</i>	⁴ D° – ² S	3856.14	22000	1	0.328			1.19	0.041		+/-	D, D	3
27	4 <i>p</i> – 4 <i>d</i>	⁴ D° – ⁴ F	3519.99	22000	1	0.557		0.95	1.17	0.196		1.09	C ⁺ , B ⁺	3
			3548.51	22000	1	0.543		0.92	1.13	0.193		1.08	D,	3

28	4 <i>p</i> – 4 <i>d</i>	⁴ D° – ⁴ P	3370.91	22000	1	0.548		1.00	1.17	0.190	1.07	C ⁺ B ⁺ , B ⁺	3
			3421.61	22000	1	0.583		1.02	1.21	0.213	1.17	B ⁺ , B ⁺	3
29	4 <i>p</i> – 4 <i>d</i>	⁴ D° – ² F	3397.90	22000	1	0.606		0.96	1.23	0.212	1.23	B ⁺ , B ⁺	3
			3430.42	22000	1	0.633		0.97	1.40	0.211	1.36	B ⁺ , B ⁺	3
30	4 <i>p</i> – 4 <i>d</i>	⁴ D° – ² D	2865.84	22000	1	0.696		1.05	0.83	<i>d</i> < 0.025	-----	B ⁺	3
31	4 <i>p</i> – 4 <i>d</i>	² D° – ⁴ D	3958.38	22000	1	0.624		0.90	0.97	0.175	0.62	B ⁺ , B ⁺	3
			3988.16	22000	1	0.594		0.86	0.91	0.223	0.78	C ⁺ , C ⁺	3
			4031.38	22000	1	0.577		0.79	0.87	0.213	0.73	D, C ⁺	3
32	4 <i>p</i> – 3 <i>d</i>	² D° – ² S	4047.48	22000	1	0.379			0.98			D	3
33	4 <i>p</i> – 4 <i>d</i>	² D° – ² F	3464.13	22000	1	0.641	1.01	0.94	1.18	0.260	0.81	C ⁺ , B ⁺	3
			3545.60	22000	1	0.667	1.01	0.96	1.19	0.251	0.74	D, C ⁺	3
34	4 <i>p</i> – 4 <i>d</i>	² D° – ² P	3204.32	22000	1	1.042		1.42	1.06	0.179	1.57	B ⁺ , B ⁺	3
			3273.32	22000	1	0.908		1.28	0.99	0.285	0.87	B ⁺ , B ⁺	3
35	4 <i>p</i> – 4 <i>d</i>	² D° – ² D	2955.39	22000	1	0.791		1.10	0.88	0.030	+/-	B ⁺ , D	3
			3014.48	22000	1	0.836		1.11	0.90			B ⁺	3
36	4 <i>p</i> –	² P° – ² F	3655.28	22000	1	0.677		0.93	1.16	0.221	0.93	D,	3

37	$4d$ $4p - 4d$	${}^2P^o - {}^2P$	3236.81	22000	1	0.933	0.75	1.29	0.34	0.189	0.37	0.39	C ⁺ B ⁺ , B ⁺	3
			3307.23	22000	1	0.931	0.72	1.36	0.51	0.350	0.66	0.48	B ⁺ , B ⁺	3
			3366.58	22000	1	0.948	0.70	1.34	0.50	0.276	0.50	0.37	B ⁺ , B ⁺	3
38	$4p - 4d$	${}^2P^o - {}^2D$	3028.91	22000	1	0.779		1.07	0.86	$ d < 0.025$		-----	C ⁺	3
			3093.40	22000	1	0.888		1.15	0.91	$ d < 0.025$		-----	B ⁺	3
39	$4p - 5s$	${}^2P^o - {}^2D$	2764.65	22000	1	0.344		1.06	0.93	0.138		0.69	C ⁺ , C ⁺	3
40	$4p - 4d$	${}^4S^o - {}^4F$	3952.73	22000	1	0.701		0.97	1.21	0.247		1.15	B ⁺ , B ⁺	3
41	$4p - 4d$	${}^4S^o - {}^4P$	3868.53	22000	1	0.695	1.01	0.97	0.59	0.365	1.05	1.80	C ⁺ , C ⁺	3
			3932.55	22000	1	0.720	1.01	0.98	0.67	0.273	0.76	1.96	C ⁺ , B ⁺	3
42	$4p - 4d$	${}^2S^o - {}^2D$	3161.37	22000	1	0.747		0.93	0.76	0.056		+/-	C ⁺ , D	3
43	$3d - 4f$	${}^2F - {}^2[3]^o$	3165.29	22000	1	0.472							C ⁺	3
			3186.17	22000	1	0.449							C ⁺	3
44	$3d - 4f$	${}^2F - {}^2[4]^o$	3046.08	22000	1	0.456			1.00	0.172		0.64	B ⁺ , B ⁺	3
			3066.89	22000	1	0.496			1.08	0.162		0.59	B ⁺ , C ⁺	3
45	$4p - 5s$	${}^2F^o - {}^2D$	3925.72	22000	1	0.747		1.06	1.01	0.335		0.85	C ⁺ , B ⁺	3
			3926.05	22000	1	0.687		0.97	0.93	0.334		0.85	D,	3

			3946.10	22000	1	0.749	1.00	1.00	0.302	0.79	B ⁺ C ⁺ ,	3
46	4 <i>p</i> - 4 <i>d</i>	² F ^o - ² G	3561.03	22000	1	0.574	0.89	1.04	0.150	1.97	B ⁺ D,	3
47	4 <i>p</i> - 4 <i>d</i>	² F ^o - ² D	3414.46	22000	1	0.671	0.66	1.63	0.279	1.79	C ⁺ C ⁺ ,	3
48	4 <i>p</i> - 4 <i>d</i>	² F ^o - ² F	3350.92	22000	1	0.680	0.71	0.96	0.227	0.92	B ⁺ B ⁺ ,	3
			3365.52	22000	1	0.665	0.70	0.92	0.219	0.88	B ⁺ B ⁺ ,	3
			3376.44	22000	1	0.839	0.91	1.17	0.309	1.28	B ⁺ B ⁺ ,	3
49	4 <i>p</i> - 4 <i>d</i>	² P ^o - ² P	3660.44	22000	1	1.158	0.73	1.92	0.214	1.65	B ⁺ B ⁺ ,	3
			3671.00	22000	1	1.104	0.70	1.84	0.253	1.85	C ⁺ D, D	3
			3754.05	22000	1	1.224	0.74	1.69	0.302	2.28	B ⁺ B ⁺ ,	3
50	4 <i>p</i> - 4 <i>d</i>	² P ^o - ² D	3639.83	22000	1	1.103	0.89	1.85	0.262	2.15	B ⁺ B ⁺ ,	3
			3680.06	22000	1	1.424	1.18	1.98			C ⁺	3
51	4 <i>p</i> - 4 <i>d</i>	² P ^o - ² S	3026.75	22000	1	1.109	0.87	1.30			B ⁺	3
			3082.98	22000	1	1.197	0.89	1.11	- 0.126	0.54	C ⁺ C ⁺ ,	3
52	3 <i>d</i> - 4 <i>f</i>	² D - ² [1] ^o	2757.30	22000	1	0.415		0.92			D	3
53	3 <i>d</i> - 4 <i>f</i>	² D - ² [3] ^o	2744.79	22000	1	0.590		1.34	0.089	0.40	B ⁺ C ⁺	3
54	3 <i>d</i> - 6 <i>f</i>	² D - ² [1] ^o	2647.84	22000	1	0.951		0.16	0.438	0.25	B ⁺ B ⁺	3

55	$4p - 4d$	$^2D^o - ^2P$	3819.02	22000	1	0.953	0.57	0.90	0.358	1.10	C ⁺ , C ⁺	3
			3825.67	22000	1	1.001	0.60	0.94	0.268	0.84	D, D	3
			3830.52	22000	1	1.139	0.70	1.08			D	3
56	$4p - 4d$	$^2D^o - ^2D$	3796.59	22000	1	1.017	0.79	1.68	0.305	1.35	C ⁺ , C ⁺	3
			3803.17	22000	1	1.086	0.86	1.80	0.374	1.72	C ⁺ , B ⁺	3
57	$4p - 4d$	$^2D^o - ^2F$	3718.21	22000	1	0.877	0.76	0.80	0.233	0.68	C ⁺ , C ⁺	3
			3737.89	22000	1	0.914	0.80	0.84	0.310	0.93	C ⁺ , C ⁺	3
58	$4p - 5d$	$^2D^o - ^4P$	3521.56	22000	1	0.619		0.34	0.176	0.26	B ⁺ , B ⁺	3
59	$3d - 4f$	$^2P - ^2[1]^o$	2924.63	22000	1	0.460		1.11	0.048	0.25	B ⁺ , D	3
			2960.24	22000	1	0.497		1.22			B ⁺	3
60	$3d - 4f$	$^2P - ^2[2]^o$	2931.48	22000	1	0.483		1.00	0.070	0.27	B ⁺ , D	3
61	$3d - 4f$	$^2D - ^2[2]^o$	3408.61	22000	1	0.591		1.14			D	3
62	$5p - 5s$	$^4D^o - ^2S$	4005.36	22000	1	1.168					D	3
The average ratio values						0.95	0.89	1.00		0.83	0.93	

Argon

Ar III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^4 \ ^3P_2$

Ionization energy: 40.735 eV = 328 550 cm⁻¹

Two experimental studies^{1,2} of Ar III Stark broadening parameters are carried out in linear pulsed discharges. First experiment is performed in gas mixture of argon and helium while the second study is in pure argon, see Key data on experiments. Among the other differences between these two experiments, one should mention line shape recording techniques and plasma radiation detection. For the first experiment¹ photomultiplier is used and line recording is performed using wavelength step by step combined with discharge shot by shot technique i.e., time resolved signal from pulsed plasma radiation. Several time-resolved radiation pulses from discharge are recorded by digital oscilloscope, accumulated at the same wavelength, and averaged. Then, fitting of recorded data is performed and line profile determined, see e.g., Fig. 5 in Ref.1. The other possibility for radiation detection is ICCD camera, which can be used for single shot line shape recording, see e.g. Ref. 2 and references therein. The same part of spectrum or whole line profile are recorded several times depending upon ICCD sensitivity and radiation intensity. Then follows the averaging procedure and line shape is displayed for line parameters measurement, see Ref. 2.

Before line shape analysis in both experiments,^{1,2} the line self-absorption test is performed. Stark widths are reported only for optically thin line profiles or for corrected weakly self-absorbed profiles.

The authors of Ref. 2 in addition to Ar III line shapes analysis performed also detailed search for Ar III Stark broadening experiments carried out in preceding experiments. Large variations of data between experiments were detected, see Fig. 1 of Ref. 2.

Here, the comparison of experimental with SC Ar III Stark broadening parameters is performed with data from Ref. 3 (denoted in Numerical data table with subscript H). Another comparison includes also SC results evaluated in this work (TW). The agreement between these two sets of calculations is very good since the average ratio of 0.93 and 0.94 is obtained respectively. The shift calculations are performed in this work only. The search for an average value of measured over theoretical shifts is

not carried out because of large variation of experimental shifts within multiplets, see Numerical data for Ar III. These variations of shifts are most likely, experimental origin. Namely, the measured A III shifts are very small (the order of magnitude 10^{-2} of an angstrom) and if interference with neighboring lines and noise occurs accurate measurement is difficult to perform with equipment used in these experiments.^{1,2}

More Ar III experimental data one can find in earlier critical reviews CR (1976, 84, 90, 02).

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Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2292.98	15	2484.11	2	2855.31	7	3344.76	6
2297.15	4	2488.86	18	2878.76	7	3352.11	6
2300.78	10	2508.91	2	2884.21	7	3358.53	6
2302.17	10	2631.86	3	3010.02	11	3361.28	6
2395.65	14	2678.35	3	3023.98	8	3471.32	13
2399.20	14	2724.79	3	3027.16	8	3472.61	5
2413.22	17	2762.16	9	3054.77	8	3480.50	5
2418.84	17	2783.60	9	3285.85	1	3960.49	12
2443.62	19	2785.23	9	3301.85	1		
2472.94	16	2824.65	9	3311.24	1		
2476.10	16	2853.31	7	3336.17	6		

Key data on experiments

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Extended low-pressure pulsed arc in gas mixture Ar72% + He28% at 133 Pa	Laser interferometry at 6328 Å	Boltzmann plot of Ar III lines and Saha equation of Ar II and Ar III lines	Plasma observed end-on Instrumental profile not reported
2	Low-pressure pulsed arc in pure argon at 0.5 kPa	Two wavelength laser interferometry	Boltzmann plot of Ar II lines	Plasma observed end-on

Numerical results for Ar III

No.	Trans. array	Mult.	Wave. (Å)	Temperature (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_H	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	4s - 4p	$^5S^o - ^5P$	3285.85	22000	1	0.149	0.73	0.84	-	-/+	C, C	2
			3301.85	30000	1.47	0.230	0.97	1.04	0.028		B+	1
				28000	1				-	-/+	B	1
				22000	1	0.148	0.72	0.87	-	-/+	B, B	2
			3311.24	30000	1.47	0.258	0.98	1.23	0.036		B+	1
				28000	1				-	-/+	C+	1

									0.014			
				22000	1	0.161	0.78	1.00	-	-/+	B, D	2
									0.039			
2	3d - 4p	³ F° - ³ F	2484.1 1	28000	1				-	-/+	D	1
			2508.9 1	28000	1				-	-/+	D	1
									0.005			
									0.003			
3	3d - 4p	³ D° - ³ D	2631.8 6	22000	1	0.098	1.02	0.91			C	2
			2678.3 5	22000	1	0.103	1.06	0.93			B	2
			2724.7 9	28000	1				0.0	----	--	1
4	3d - 4p	³ D° - ³ P	2297.1 5	28000	1				-	-/+	B	1
									0.017			
5	4s - 4p	³ D° - ³ D	3472.6 1	30000	1.47	0.320	1.12	1.18			B+	1
				28000	1				-	0.91		1
									0.051		B+	
			3480.5 0	30000	1.47	0.300	1.04	1.01			B+	1
				28000	1				-	0.70		1
									0.050		B+	
6	4s - 4p	³ D° - ³ F	3336.1 7	30000	1.47	0.312	1.14	1.14			B+	1
				28000	1				-	0.39		1
									0.025		B+	
				22000	1	0.185	0.86	0.90	-	0.70	B, C	2
									0.049			
			3344.7 6	30000	1.47	0.325	1.19	1.19			B+	1

				28000	1				-	0.25	B	1
									0.016			
				22000	1	0.166	0.78	0.80	-	0.55	B, B	2
									0.039			
			3352.1	30000	1.47	0.309	1.12	1.29			B+	1
			1									
				28000	1				0.0	----	--	1
			3358.5	30000	1.47	0.311	1.14	1.11			B+	1
			3									
				28000	1				0.0	----	--	1
				22000	1	0.160	0.75	0.76	-	0.49	C, B	2
									0.036			
			3361.2	30000	1.47	0.318	1.16	1.31			B+	1
			8									
7	4s -	³ D° -	2853.3	22000	1	0.119	0.77	0.75			B	2
	4p	³ P	1									
			2855.3	22000	1	0.123	0.80	0.77	-	0.59	B, A	2
			1	28000	1				0.032	0.37	B	1
									-			
									0.017			
			2878.7	22000	1	0.116	0.75	0.73			C	2
			6									
			2884.2	22000	1	0.112	0.72	0.68			C	2
			1									
8	4s -	³ P° -	3023.9	30000	1.47	0.204	0.98	0.96			B+	1
	4p	³ D	8									
				28000	1				-	0.38	B	1
									0.018			
				22000	1	0.134	0.82	0.83	-	0.96	C, D	2
									0.051			
			3027.1	30000	1.47	0.184	0.88	0.97			B+	1

16	$4p - 4d$	${}^3F - {}^3F^{\circ}$	2472.9 4	28000	1	- 0.018	0.36	B	1
			2476.1 0	28000	1	- 0.005	0.10	D	1
17	$4p - 4d$	${}^3F - {}^3G^{\circ}$	2413.2 2	28000	1	- 0.032	0.95	B+	1
			2418.8 4	28000	1	- 0.016	0.48	B	1
18	$4p - 4d$	${}^3P - {}^3P^{\circ}$	2488.8 6	28000	1	- 0.018	0.37	B	1
19	$4p - 5s$	${}^3P - {}^3D^{\circ}$	2443.6 2	28000	1	- 0.019	0.34	B	1

The average ratio values

0.93 0.94

In Ref. 1 the authors report, for every spectral line, only one Stark shift data for temperature interval 26000 - 30000 K.

In this Table the average temperature value of 28000 K is given.

Barium

Ba I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 6s^2 \ ^1S_0$

Ionization energy: 5.2116646 eV = 42 034.91 cm⁻¹

Laser induced plasma was a plasma source used for measurement of Stark broadening parameters of Ba I spectral lines.¹ The details of the experimental setup one can find in the table Kay data on experiments. Important information about plasma diagnostics (electron density and temperature) is discussed in Ref. 2. The electron density is determined from the Stark broadened halfwidth of Si I 390.55 nm line with an estimated uncertainty of 20%. Measured Stark halfwidths of Ba I lines are reported in Table 4 of Ref. 1 for $N_e = 10^{17}$ cm⁻³ without specifying electron temperature. In the general statement about uncertainty of measured Ba I Stark broadening parameters, the authors¹ claim the uncertainty of 20% (B⁺) for the results of all lines. Since the Stark broadening parameters are reported normalized to $N_e = 10^{17}$ cm⁻³ we increased originally estimated uncertainty for another 20 %, which gives now total uncertainty (B), see Numerical results for Ba I. Since the authors¹ did not specify electron temperature for reported Ba I Stark broadening parameters we introduce value of 9200 K from the Boltzmann plot of Ba I lines, see Fig.6 in Ref .1. After the inspection of Ba I results one can notice large difference (almost factor of five) of Stark halfwidths, within multiplet M9. The authors did not offer any explanation for this difference and uncertainty is reduced to C⁺.

The comparison of our SC calculations (TW) (Ref. 3 (DSB) reports results for a single line only) shows large variations of the ratios measured over calculated values and therefore, the average value is not introduced in Numerical results for Ba I. For multiplets M2, M4, M5 and M7, our SC calculations predict Stark wavelength shift in the opposite direction from experiment.____

References

¹J. Hermann, C. Gerhard, E. Axente, C. Dutouquet, Spectrochim. Acta B **100**, 189 (2014).

²Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet, M.

Sentis, W. Viöl, Spectrochim. Acta B **101**, 32 (2014).

³M. S. Dimitrijević, S. Sahal-Bréchet, Bull. Astron. Belgrade **154**, 61 (1996).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
3993.40	5	5535.48	1	6482.91	6	7280.30	2
4283.10	7	5777.62	8	6527.31	3		
4579.64	9	6063.11	4	6595.33	3		
4691.61	9	6110.78	4	7059.94	2		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: barite crown glass positioned in chamber filled with argon at 5×10^4 Pa or air at atmospheric pressure	Halfwidth of Si I 390.55 nm line	Boltzmann plot of Ba I and B II spectral lines and the ratio of Si I and Si II lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam There is no clear explanation about electron density measurement

Numerical results for Ba I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{DSB}	w_m/w_{TW}	d_m (Å)	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	$6s^2 - 6s6p$	$^1\text{S} - ^1\text{P}^o$	5535.48	9200	1	0.35	1.42	0.70	0.10	2.54	0.90	C ⁺ , C ⁺	1
2	$6s5d - 5d6p$	$^3\text{D} - ^3\text{F}^o$	7059.94 7280.30	9200 9200	1 1	0.39 0.45		0.34 0.33	0.16 0.06		+/- +/-	C ⁺ , C ⁺ C ⁺ , C ⁺	1 1
3	$6s5d - 5d6p$	$^3\text{D} - ^3\text{D}^o$	6527.31 6595.33	9200 9200	1 1	0.60 0.60		0.26 0.21				C ⁺ C ⁺	1 1
4	$6s5d - 5d6p$	$^3\text{D} - ^3\text{P}^o$	6063.11 6110.78	9200 9200	1 1	0.38 0.32		0.33 0.28	0.18 0.19		+/- +/-	C ⁺ , C ⁺ C ⁺ , C ⁺	1 1

5	$6s5d - 6s4f$	$^3D - ^3F^o$	3993.40	9200	1	0.39	3.09	0.15	+/-	C ⁺ , C ⁺	1
6	$6s5d - 5d6p$	$^1D - ^1F^o$	6482.91	9200	1	0.60	0.48			C ⁺	1
7	$6s5d - 6s4f$	$^1D - ^1F^o$	4283.10	9200	1	0.69	3.46	0.18	+/-	C ⁺ , C ⁺	1
8	$6s6p - 6s6d$	$^3P^o - ^3D$	5777.62	9200	1	1.20	0.15	0.52	0.13	C ⁺ , C ⁺	1
9	$6s6p - 6p^2$	$^3P^o - ^3P$	4579.64	9200	1	0.48	3.06	0.15	0.56	C, C	1
			4691.61	9200	1	0.10	0.64			C	1

Barium

Ba II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 s^2 S_{1/2}$

Ionization energy: $10.003826 \text{ eV} = 80\,686.30 \text{ cm}^{-1}$

For the study of Stark broadening parameters of Ba II spectral lines, the authors^{1,2} used laser induced plasma. The details of the experimental setup one can find in the table Kay data on experiments. The additional information about plasma diagnostics (electron density and temperature) are given and discussed in Ref. 2. The electron density is determined from the Stark broadened halfwidth of Si I 390.55 nm line. Measured Stark halfwidths of Ba II lines are reported in the table 4 of Ref. 1 for $N_e = 10^{17} \text{ cm}^{-3}$ without specifying the uncertainty for each particular result. From the general statement, in Ref. 1, one can conclude that the uncertainty of measured Ba II Stark broadening parameters is 20%. The electron temperature for reported Ba II Stark broadened lines is determined from the Boltzmann plot of Ba II lines, see Fig.6 in Ref. 1. In a single case² the electron temperature of 11200 K, which is reported in the table of Numerical results for Ba II is derived from the graphical presentation of plasma diagnostic data.

The comparison of SC Stark halfwidths calculations, Ref. 3 (DSB) and this work (TW) with experimental results shows large scatter of the ratios measured over calculated values but with relatively small mutual difference between average ratios for these two sets (0.76 and 0.83 for DSB and TW columns, respectively), see Numerical results for Ba II. For the Stark shifts smaller number of ratios is reported because both SC calculations, DS and TW, predict shifts of the opposite wavelength direction in comparison with experiment. Nevertheless, the average DSB and TW values for the Stark shifts are reasonably close.

CR (1976, 84).

References

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
3891.78	4	4166.00	4	4899.93	3	5853.68	2
4130.65	4	4524.93	3	4934.08	1	6496.90	2

¹J. Hermann, C. Gerhard, E. Axente, C. Dutouquet, *Spectrochim. Acta B* **100**, 189 (2014).

²C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet, M. Sentis, W. Viöl, *Spectrochim. Acta B* **101**, 32 (2014).

³M. S. Dimitrijević, S. Sahal-Bréchet, *Bull. Astron. Belgrade* **154**, 61 (1996).

Finding list

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: barite crown glass positioned in chamber filled with argon at 5×10^4 Pa or air at atmospheric pressure	Stark broadening of Si I 3905.5 Å line	Boltzmann plot of Ba I and B II spectral lines and the ratio of Si I and Si II lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam There is no clear explanation about electron density measurement
2	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the generating laser beam Plasma divided in zones and calculated plasma parameters for each zone

Numerical results for Ba II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{DSB}	w_m/w_{TW}	d_m (Å)	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	6s - 6p	$^2\text{S} -$ $^2\text{P}^o$	4934.08	9700	1	0.26	0.41	0.57	- 0.06	0.60	-/+	C ⁺ , C ⁺	1
2	5d - 6p	$^2\text{D} -$ $^2\text{P}^o$	5853.68 6496.90	9700 9700	1 1	0.68 0.80	0.73 0.86	1.07 0.97	0.14 0.12	+/- +/-	0.60 +/-	C ⁺ , C ⁺ C ⁺ , C ⁺	1 1
3	6p - 7s	$^2\text{P}^o -$ ^2S	4524.93 4899.93	9700 9700	1 1	1.43 1.22	1.11 0.95	1.24 0.91	0.48 0.51	0.95 0.86	0.75 0.68	C ⁺ , C ⁺ C ⁺ , C ⁺	1 1
4	6p - 6d	$^2\text{P}^o -$ ^2D	3891.78 4130.65 4166.00	9700 11200 9700 9700	1 1 1 1	0.83 0.83 0.93 0.93	0.77 0.82 0.77 0.76	0.67 0.69 0.66 0.65	0.33 0.33 0.38 0.38	0.61 0.65 0.62 0.61	0.52 0.54 0.52 0.51	C ⁺ , C ⁺ C ⁺ , C ⁺ C ⁺ , C ⁺ C ⁺ , C ⁺	1 2 1 1
The average ratio values							0.80	0.83		0.70	0.59		

Cadmium

Cd III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} {}^1S_0$

Ionization energy: 37.468 eV = 302 200 cm⁻¹

The authors^{1,2} used low pressure linear plasma source similar to the one used for the study of Au I and Au II line shapes, see these Reports. The cadmium atoms are sputtered from the cadmium (99.9% purity) cylindrical plates located inside the axial part of the discharge tube close to its ends. The position of the cylindrical plates each 20 mm long provides uniform distribution of the sputtered Cd atoms along the optical axis of the discharge

The details of experiment and plasma diagnostic procedure one can find in Key data on experiment. Here should be mentioned only that silicon, from which spectral lines, were used in procedure for electron temperature determination, are obtained by sputtering from the glass discharge tube.

The table of Numerical results for Cd III, contains apart from the results for Cd III, the transitions, multiplets and wavelengths, which are all taken from Ref.1. The line wavelengths are set in the same order as in the NIST site³ except the line 2322.56 Å, which in Ref. 3 is not listed. The spectroscopic notation in Ref. 3 is not reported, only wavelengths are given. Due to the lack of energy levels, the semiclassical calculations are not performed. The transition and multiplet notation in the table of Numerical results are given as presented in Ref. 1 where the authors used notation from Ref. 4.

With the same equipment and plasma diagnostics technique the same group of authors made an attempt to extend Stark broadening parameters measurements of triply ionized Cd lines. The authors² measured Stark halfwidths of 12 lines, see table of Numerical results but they could not determine to which ionization stage spectral lines and Stark broadening parameters belong either to Cd III or Cd IV since energy level data and wavelengths are not available. These results however, may be of some interest for future studies of line broadening of doubly and/or triply ionized cadmium lines.

References

¹S. Bukvić, S. Djeniže, A. Srećković, Z. Nikolić, Phys. Lett. A **373**, 2750 (2009).

²S. Djeniže, A. Srećković, S. Bukvić, Eur. Phys. J. D **62**, 185 (2011).

³NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

⁴Th. A. M. van Kleef, Y. N. Joshi, P. Uijlings, Phys. Scr. **22**, 353 (1980).

Key data on experiments

Ref	Plasma source		Method of measurement					Remarks		
			Electron density		Temperature					
					Electron					
	No.	Trans. array	Mult.	Wave- (Å)	Temp. (K)	Intensity ratios of Si III/Si IV and OII/OIII lines	w_m (Å)	Acc.	Ref.	
1	Linear low-pressure pulsed arc with the discharge gas mixture of 90% He + 7% N ₂ + 3% O ₂ at 665 Pa		1	Stark half width of the He II P _α spectral line	19000	0.5	0.050	B	1	Plasma observed end-on along the axis of discharge
	1	5s - 5p	¹ D - ³ P ^o	2004.07	19000	0.5	0.050	B	1	
		5s - 5p	¹ D ^o - ³ P	2039.83	19000	0.5	0.040	B	1	
		5s - 5p	³ D ^o - ³ P	2045.61	19000	0.5	0.039	B	1	
		5p - a	³ F ^o - ³ F	2087.91	19000	0.5	0.028	C ⁺	1	
		5s - 5p	³ D - ³ P ^o	2100.47	19000	0.5	0.038	B	1	
2	Linear low-pressure pulsed arc with the discharge gas mixture of 90% He + 7% N ₂ + 3% O ₂ at 665 Pa		1	Stark half width of the He II P ₂ 2344.3 Å line	19000	0.5	0.056	B	1	Plasma observed end-on along the axis of discharge
		5s - 5p	¹ D ^o - ³ F	2322.56	19000	0.5	0.066	B	1	
		5p - a	¹ D ^o - ³ F	2418.24	19000	0.5	0.048	B	1	
		5s - 5p	¹ D ^o - ³ F	2426.36	19000	0.5	0.054	B	1	
		5s - 5p	³ F ^o - ³ F	2499.81	19000	0.5	0.056	B	1	
		5p - a	¹ D ^o - ³ F	2618.81	19000	0.5	0.078	B	1	
		5p - a	¹ F ^o - ³ F	2630.56	19000	0.5	0.063	B	1	
		5p - a	³ D ^o - ³ F	2766.99	19000	0.5	0.045	B	1	
		5p - a	³ D ^o - ³ F	2805.59	19000	0.5	0.056	B	1	
		5p - a	¹ F ^o - ³ F	3035.72	19000	0.5	0.056	B	1	
Numerical III	2			3048.82	19000	0.52	0.144	C ⁺	2	results for Cd
				3053.10	19000	0.52	0.146	C ⁺	2	
				3064.99	19000	0.52	0.150	C ⁺	2	
				3084.86	19000	0.52	0.188	C ⁺	2	
				3095.45	19000	0.52	0.178	C ⁺	2	
				3118.91	19000	0.52	0.152	C ⁺	2	
				3121.80	19000	0.52	0.166	C ⁺	2	
				3124.40	19000	0.52	0.172	C ⁺	2	
				3129.20	19000	0.52	0.188	C ⁺	2	
				3210.10	19000	0.52	0.158	C ⁺	2	
				3217.80	19000	0.52	0.136	C ⁺	2	
				3283.82	19000	0.52	0.132	C ⁺	2	

Calcium

Ca I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 \ ^1S_0$

Ionization energy: $6.11315547 \text{ eV} = 49\,305.9240 \text{ cm}^{-1}$

At the beginning of this report, it should be mentioned that, in several cases, similar technique is applied by Burger and Hermann¹ for a number of elements and ions as used for the measurement of Stark broadening parameters of Ca I lines. To avoid numerous repetitions of similar details we describe here more details than usual for experiments of Stark broadening measurement. Then, for other neutral and ion species instead of repetition identical lengthy details, the report for Ca I is quoted.

The experimental setup: the plasma radiation is collected by imaging the plasma plume with two lenses onto the entrance of an optical fiber. The optical axis of the lenses was tilted by 15° with respect to the incident laser beam, which is perpendicular to the target surface and used for plasma generation. In such a way a cylindrical volume of about 3 mm diameter was observed. The fiber was coupled to the entrance slit of an echelle spectrometer. The radiation detection is performed using an intensified CCD matrix detector.

The determination of Stark broadening parameters consists of the following successive measurement steps: (i) the plasma temperature T (assuming LTE, and uses Boltzmann plot), (ii) the electron density N_e (from halfwidth of the H_α line) and (iii) relative fractions of elements are deduced for spectra recorded for different times using an iterative procedure.

Once the plasma is characterized, the Stark width and shift of non-hydrogenic lines are deduced from best agreement of measured profile (typically around $N_e = 10^{17} \text{ cm}^{-3}$ and T between 6000 K and 14000 K) with calculated values for non-hydrogenic line profile, which may be Gaussian (Doppler dominated) or Voigt depending upon mutual ratio of Gaussian and Lorentzian (Stark) profile. In this way the authors avoid application of laborious Abel inversion procedure.

Unfortunately, in the data table of Ref. 1, with the reported results temperatures are not mentioned with measured Stark broadening parameters. The temperature value of 11000 K, which is given in Numerical table for Ca I results, is derived from graphical presentation of plasma diagnostic data, see Fig. 6 in Ref.1.

As far as SC calculations some difficulties with the lack of perturbing levels is met, see Ref. 2 (G) and for the multiplets 4, 5 and 8 Stark broadening parameters are not calculated. These multiplets contain two-electron transitions from the upper energy levels for which the completeness of perturbing levels ($\Delta S/S$) doesn't meet the $\Delta S/S \sim 0$

condition.² Furthermore, the comparison with theoretical data, in multiplets 6 and 7 are also omitted because $\Delta S/S$ are below limit of -0.6. Consequently, the average values for different sets of calculations are not given also. For comparison with experimental results, apart from Ref. 2 and this work (TW) another set^{4, 5} (DSB) of SC calculations is used.

CR (1976).

References

¹M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).

²H. R. Griem, *Spectral line broadening by plasmas*, Academic Press, New York, (1974).

³NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

⁴M. S. Dimitrijević and S. Sahal-Bréchet, *Serb. Astron. J.* **161**, 39 (2000).

⁵M. S. Dimitrijević and S. Sahal-Bréchet, *Astron. Astrophys. Suppl. Ser.* **140**, 191 (1999).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2994.96	5	4302.53	4	4455.89	3	5857.45	8
2997.31	5	4307.74	4	4456.61	3	6122.22	2
3000.86	5	4318.65	4	5581.97	7	6439.07	6
3006.86	5	4425.44	3	5588.76	7	6462.57	6
3009.21	5	4434.96	3	5590.12	7	6493.78	6
4226.73	1	4435.69	3	5594.47	7		
4298.99	4	4454.78	3	5598.49	7		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in a vacuum chamber filled with argon at 5×10^4 Pa	H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Ca I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	$4s^2 - 4p$	$^1S - ^1P^o$	4226.73	11000	1	0.32	2.40	2.54	1.80	0.06	1.50	0.76	0.68	D, C	1
2	$4p - 5s$	$^3P^o - ^3S$	6122.22	11000	1	1.65	1.03	1.42	1.04	0.75	0.74	0.81	0.69	B, B	1
3	$4p - 4d$	$^3P^o - ^3D$	4425.44	11000	1	2.00	1.24	1.59	1.13					B	1
			4434.96	11000	1	2.00	1.24	1.58	1.13					B	1
			4435.69	11000	1	2.00	1.24	1.58	1.13					B	1
			4454.78	11000	1	2.00	1.23	1.57	1.12					B	1
			4455.89	11000	1	2.00	1.23	1.57	1.12					B	1
			4456.61	11000	1	2.00	1.23	1.56	1.12					B	1

4	$4p - 4p^2$	$^3P^o - ^3P$	4298.99	11000	1	0.40	- 0.08	B, C	1
			4302.53	11000	1	0.40	- 0.08	B, C	1
			4307.74	11000	1	0.40	- 0.08	B, C	1
			4318.65	11000	1	0.40	- 0.08	B, C	1
5	$4p - 3d^2$	$^3P^o - ^3P$	2994.96	11000	1	0.23		B,	1
			2997.31	11000	1	0.23	0.044	C ⁺	1
			3000.86	11000	1	0.23	0.044	B,	1
			3006.86	11000	1	0.23	0.044	C ⁺	1
			3009.21	11000	1	0.23	0.044	B,	1
							0.044	C ⁺	
6	$4s - 4p$	$^3D - ^3F^o$	6439.07	11000	1	0.66	0.14	B,	1
			6462.57	11000	1	0.66	0.14	C ⁺	1
			6493.78	11000	1	0.66	0.14	B,	1
								C ⁺	
								B,	
7	$4s - 4p$	$^3D - ^3D^o$	5581.97	11000	1	0.90	0.28	B,	1
			5588.76	11000	1	0.90	0.28	C ⁺	1
			5590.12	11000	1	0.90	0.28	B,	1
			5594.47	11000	1	0.90	0.28	C ⁺	1
			5598.49	11000	1	0.90	0.28	B,	1
								C ⁺	
8	$4p -$	$^1P^o -$	5857.45	11000	1	2.60	1.00	B,	1
								C ⁺	

 $4p^2 \quad {}^1D$

Calcium

Ca II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 S_{1/2}$

Ionization energy: $11.871719 \text{ eV} = 95\,751.87 \text{ cm}^{-1}$

Three similar experiments¹⁻³ are used to determine Stark broadening parameters of Ca II lines. For all experiments plasma is induced by Nd:YAG lasers.^{1,3} In order to test measured line profiles whether they are optically thin, the curve of growth method is applied. For this purpose glasses with different known concentrations of calcium are prepared and used after laser irradiation for line self-absorption test. The description of experimental details and plasma diagnostics for Ref. 3 is given in Report for Ca I.

Apart from experimental results for Stark widths and shifts in the table Numerical results for Ca II the corresponding SC theoretical data for electron impact halfwidths and shifts are included in the comparison. This is achieved by introducing in the table of results the ratio of experimental over theoretical results evaluated using theoretical approaches described in Refs. 4 (G) and 5 (DSB) and the one used in this work (TW).

In addition it is important to notice that temperature values, reported in the table Numerical results from Refs. 1 and 3, are derived using graphical presentation of plasma diagnostic data, see Fig. 7 in Ref 1 and Fig. 6 in Ref. 3.

CR (1976, 84, 90, 02).

References

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- ²J. A. Aguilera, C. Aragón, J. Manrique, *Month. Not. Roy. Astron. Soc.* **444**, 1854 (2014).
- ³M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).
- ⁴H. R. Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
- ⁵M. S. Dimitrijević, S. Sahal Bréchet, J. Quant. Spectrosc. Radiat Transfer **49**, 157 (1993).

Finding list

Wavelengt	Wavelengt	Wavelengt	Wavelengt
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h (Å)	No.	h (Å)	No.	h (Å)	No.	h (Å)	No.
2103.24	6	2197.97	5	3179.33	4	3933.66	1
2112.76	6	2208.61	5	3706.03	3	3968.47	1
2131.51	2	3158.87	4	3736.90	3		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and brite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone
2	Nd:YAG laser at 1064 nm Single pulse 60 mJ, 4.5 ns, repetition rate 20 Hz Target: fused glass discs with different calcium percentage in air at atmospheric pressure	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Fe II lines	Plasma observing end-on under small angle with incident laser beam
3	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Ca II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	4s - 4p	$^2\text{S} -$ $^2\text{P}^o$	3933.66	11200	1	0.17	0.59	0.78	0.65	-	0.32	1.03	0.44	C^+ ,	1
				14000	1	0.17	0.63	0.83	0.70	0.04	0.23	0.75	0.32	C^+	2
			3968.47	14000	1	0.16	0.59	0.77	0.70	-	0.23	0.73	1.39	B^+ ,	2
2	3d - 5p	$^2\text{D} -$ $^2\text{P}^o$	2131.51	14000	1	0.27	1.03	1.22	1.06	0.027				B^+ ,	
										-				B^+ ,	
										0.027				B^+	2
3	4p - 5s	$^2\text{P}^o -$ ^2S	3706.03	14000	1	0.66	1.05	1.15	1.07	0.28	1.06	1.04	0.83	B^+ ,	2
				11000	1	0.79	1.19	1.25	1.22	0.47	1.78	1.62	1.33	B^+	3
				14000	1	0.67	1.05	1.15	1.07	0.29	1.08	1.06	0.85	B, B	2
				11000	1	0.79	1.17	1.23	1.20	0.47	1.75	1.59	1.31	B^+ ,	3
4	4p - 4d	$^2\text{P}^o -$ ^2D	3158.87	14000	1	0.53	1.10	1.31	1.15	0.19	0.78	1.06	1.11	B, B	
														B^+ ,	2
														B^+	2
5	4p - 6s	$^2\text{P}^o -$ ^2S	2197.79	14000	1	0.77	1.35		1.36	0.26	0.83		0.82	B^+ ,	2
														B^+	2
														B^+ ,	

Carbon

C I

Ground state: $1s^2 2s^2 2p^2 \ ^3P_0$

Ionization energy: $11.2602880 \text{ eV} = 90\,820.348 \text{ cm}^{-1}$

Stark broadening parameters for the C I line 2478.56 \AA are measured¹ in plasma ablated from hydrated calcium sulfate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) target where this line is excited as an impurity line. Since, the description of the C I line experiment¹ and experimental procedure is almost identical with the one for Ca I lines¹ more detailed description of C I measurements one can find in Ca I report._

As far as SC results used for comparison with experimental C I line Stark broadening parameters, only results from Ref. 2 (G) and data calculated within this work (TW) are available.

CR (1976, 84, 90, 02, 09).

References

¹M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).

²H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974)

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in vacuum chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed line shape spectra

Numerical results for C I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{TW}	Acc.	Ref.
1	$2p^2 - 3s$	$1S - 1P^o$	2478.56	11000	1	0.14	1.83	1.53	0.08	1.66	1.19	C, C ⁺	1

Chromium

Cr II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 \ ^6S_{5/2}$

Ionization energy: 16.486305 eV = 132 971.02 cm⁻¹

Aguilera *et al.*¹ measured Stark widths and shifts of ultra-violet Cr II lines in a laser induced plasma at atmospheric pressure in air, see Key data on experiment. The target is made of fused glass samples with various concentrations of chromium employed for control self-absorption of the studied Cr II lines, most of them first time measured. The only exceptions are earlier observed three Cr II lines² in the plasma of electromagnetic T-tube. It should be noted here that Stark widths, reported in Ref. 2, are larger by a factor of 3 than data in Ref 1. In the case of Stark shifts the differences are much larger.

In the experiment¹ precautions are taken to determine high quality Cr II Stark broadening and shift parameters, which are usually with narrow halfwidth and small shift, in the picometers range

For the accuracy estimation of measured Stark broadening and shift the authors¹ took into account all precautions to check effects, which may interfere with line shape and shift of measurements in this type of laser induced plasma. To illustrate some details of this work we describe an example of relative experimental error estimation of the Stark widths. The estimated error of 15 per cent is obtained by adding quadratically the error of the electron density (11 per cent), the error caused by self-absorption (10 per cent) and the uncertainty due to plasma inhomogeneity (3 per cent). Unfortunately, this way of estimation of relative error implies equal error for Stark halfwidths in the whole range of observed wavelengths (about 1400 Å) with 83 Cr II lines within 45 multiplets. This is not very likely since in this large range some of studied lines interfere with other Cr II and impurity lines and estimated error may vary also. Nevertheless, the accuracy of present Cr II Stark halfwidths is high for this type of experiments with B⁺ estimated accuracy.

In the case of the Stark shifts the minimum absolute error due to resolution is 0.1 pm. Further the authors¹ claim "... for shifts clearly exceeding this value, a relative error of 11 per cent is estimated from the electron density uncertainty and the plasma inhomogeneity, assuming that self-absorption does not involve a shift of lines." Since the authors¹ did not

defined quantitatively meaning of “clearly exceeding” we estimated relative error with 11 per cent whenever shift is larger than 7×0.1 pm.

Here also should be noted that is not clear for which temperature are reported experimental results in Ref. 1. It is written only that results are given for temperature interval 12000 - 16300 K and electron density of $1 \times 10^{17} \text{ cm}^{-3}$. The temperature in the table Numerical results for Cr II is derived from graphical presentation of plasma diagnostic results of Ref 3 where is described the same experiment as in Ref. 1.

Theoretical calculations based on the semiclassical perturbation approach are reported by Simić *et al.*⁴ for Cr II multiplets M1, M11 and M13 and Dimitrijević *et al.*⁵ for multiplets M3, M5, M7, M8 and M9 denoted in the table with (DRS). The comparison with SC calculated_results in this work are in separate columns denoted with (TW). Within these, results for multiplets M12, M14-M16, M22, M23-M126, M28-M30, M32-M39 and M41-M44 are missing because $\Delta S/S$ is out of -0.6 limit.

The search for an average value of measured over theoretical shifts is not carried out because of large variation of experimental shifts within multiplets.

CR (1990).

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Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2055.60	1	2712.31	4	2860.93	2	3118.65	8
2061.58	1	2727.26	23	2862.57	2	3120.37	8
2107.95	10	2743.64	3	2870.43	9	3122.60	25
2121.26	16	2748.98	3	2880.86	9	3124.98	8
2215.06	39	2750.73	3	2927.08	42	3128.70	8
2297.17	12	2751.87	3	2930.85	15	3132.06	8
2314.72	12	2757.72	3	2935.13	15	3147.23	8
2397.75	14	2762.59	3	2936.93	22	3152.22	32
2416.40	38	2766.54	3	2941.96	45	3172.08	31
2534.34	6	2774.43	43	2961.72	15	3180.70	11
2573.53	37	2785.69	27	2966.04	21	3183.33	33
2575.79	36	2792.16	27	2971.90	17	3209.18	11
2584.11	20	2800.77	26	2976.71	15	3291.77	30
2653.58	4	2832.45	29	2979.74	17	3295.43	24
2666.01	5	2835.63	2	2989.19	17	3306.96	44
2668.71	5	2838.78	40	3003.92	21	3342.58	7
2671.81	5	2840.02	18	3028.12	34	3360.29	13
2672.83	4	2843.25	2	3040.92	28	3368.05	7
2678.79	5	2849.84	2	3041.72	35	3421.21	7
2691.04	5	2851.35	18	3050.13	28	3422.74	7
2693.53	19	2855.67	2	3107.57	41		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm Single pulse 60 mJ, 4.5 ns, repetition rate 20 Hz Target: glass sample of chromium oxide in air at atmospheric pressure	Stark broadening of the H_{α} line	Boltzmann plot of seven Fe II lines	Plasma observed end-on under “small” undefined angle in respect to laser beam which generates plasma.

Numerical results for Cr II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{DRS}	w_m/w_{TW}	d_m (Å)	d_m/d_{DRS}	d_m/d_{TW}	Acc.	Ref.
1	$3d^5 - 4p$	a $^6S - z \ ^6P^o$	2055.60	12300	1	0.037	1.09	0.84	0.01	+/-	0.82	B ⁺ ,	1
			2061.58	12300	1	0.034	1.00	0.77	4	+/-	0.80	B ⁺	1
									0.01 4			B ⁺ , B ⁺	
2	$4s - 4p$	a $^6D - z \ ^6F^o$	2835.63	12300	1	0.050		0.56	0.00		0.04	B ⁺ ,	1
			2843.25	12300	1	0.051		0.59	1		----	B ⁺	1
			2849.84	12300	1	0.051		0.58	0.00		-/+	B ⁺ ,	1
			2855.67	12300	1	0.050		0.56	0			B ⁺	1
			2860.93	12300	1	0.050		0.56	-		-/+	B ⁺ ,	1
			2862.57	12300	1	0.047		0.54	0.001			B ⁺	1
									- 0.002			B ⁺ , B ⁺ B ⁺	
3	$4s - 4p$	a $^6D - z \ ^6P^o$	2743.64	12300	1	0.051	0.53	0.60				B ⁺	1
			2748.98	12300	1	0.050	0.52	0.59				B ⁺	1
			2750.73	12300	1	0.051	0.53	0.60	-	0.11	-/+	B ⁺ ,	1
			2751.87	12300	1	0.048	0.49	0.57	0.001	0.11	-/+	B ⁺	1
			2757.72	12300	1	0.047	0.48	0.56	-	0.11	-/+	B ⁺ ,	1
			2762.59	12300	1	0.045	0.46	0.52	0.001			B ⁺	1
			2766.54	12300	1	0.044	0.45	0.50	-	0.11	0.04	B ⁺ ,	1
									0.001			B ⁺ B ⁺	

									-			B ⁺ ,	
								0.001				B ⁺	
4	4s -	a ⁶ D - z ⁴ P ^o	2653.58	12300	1	0.053		0.62	-		0.03	B ⁺ ,	1
	4p		2672.83	12300	1	0.054		0.62	0.001		0.07	B ⁺	1
			2712.31	12300	1	0.059		0.67	-		0.06	B ⁺ ,	1
									0.002			B ⁺	
									-			B ⁺ ,	
									0.002			B ⁺	
5	4s -	a ⁶ D - z ⁶ D ^o	2666.01	12300	1	0.048	0.48	0.60	0.00	+/-	0.11	B ⁺ ,	1
	4p		2668.71	12300	1	0.046	0.46	0.57	3	+/-	0.04	B ⁺	1
			2671.81	12300	1	0.046	0.46	0.57	0.00	+/-	0.07	B ⁺ ,	1
			2678.79	12300	1	0.050	0.49	0.61	1			B ⁺	1
			2691.04	12300	1	0.043	0.42	0.53	0.00	+/-	0.11	B ⁺ ,	1
									2			B ⁺	
												B ⁺	
									0.00			B ⁺ ,	
									3			B ⁺	
6	4s -	a ⁶ D - z ⁴ F ^o	2534.34	12300	1	0.053		0.67				B ⁺	1
	4p												
7	4s -	a ⁴ D - z ⁴ P ^o	3342.58	12300	1	0.087	0.30	0.67	-	0.02	0.05	B ⁺	1
	4p		3368.05	12300	1	0.091	0.31	0.66	0.002	0.02	0.04	B ⁺	1
			3421.21	12300	1	0.089	0.30	0.64	-			B ⁺	1
			3422.74	12300	1	0.085	0.28	0.62	0.002			B ⁺	1
8	4s -	a ⁴ D - z ⁴ F ^o	3118.65	12300	1	0.076	0.28	0.62	-	0.02	0.05	B ⁺ ,	1
	4p		3120.37	12300	1	0.075	0.27	0.63	0.002	0.02	0.06	B ⁺	1
			3124.98	12300	1	0.074	0.27	0.62	-	0.01	0.03	B ⁺ ,	1
			3128.70	12300	1	0.071	0.26	0.63	0.002	0.02	-/+	B ⁺	1
			3132.06	12300	1	0.072	0.26	0.60	-	0.01	0.03	B ⁺ ,	1
			3147.23	12300	1	0.075	0.27	0.66	0.001	0.02	-/+	B ⁺	1
									-			B ⁺ ,	
									0.002			B ⁺	

									-			B ⁺ ,	
									0.001			B ⁺	
									-			B ⁺ ,	
									0.002			B ⁺	
9	4s -	a ⁴ D - z ⁴ D ^o	2870.43	12300	1	0.065	0.29	0.63	0.00	+/-	0.13	B ⁺ ,	1
	4p		2880.86	12300	1	0.069	0.31	0.68	4	+/-	0.09	B ⁺	1
									0.00			B ⁺ ,	
									3			B ⁺	
10	4s -	a ⁴ D - y ⁴ F ^o	2107.95	12300	1	0.041		0.54				B ⁺	1
	4p												
11	3d ⁵ -	a ⁴ G - z ⁴ F ^o	3180.70	12300	1	0.107	1.01	0.96				B ⁺	1
	4p		3209.18	12300	1	0.109	1.01	0.96				B ⁺	1
12	3d ⁵ -	a ⁴ G - z	2297.17	12300	1	0.047			0.01			B ⁺ ,	1
	4p	⁴ H ^o	2314.72	12300	1	0.050			6			B ⁺	1
									0.01			B ⁺ ,	
									5			B ⁺	
13	3d ⁵ -	b ⁴ D - z	3360.29	12300	1	0.121	1.14	0.93				B ⁺	1
	4p	⁴ D ^o											
14	3d ⁵ -	b ⁴ D - y ⁴ P ^o	2397.75	12300	1	0.059			0.01			B ⁺ ,	1
	4p								6			B ⁺	
15	4s -	b ⁴ P - y ⁴ D ^o	2930.85	12300	1	0.066			-			B ⁺ ,	1
	4p		2935.13	12300	1	0.066			0.001			B ⁺	1
			2961.72	12300	1	0.062						B ⁺	1
			2976.71	12300	1	0.060			-			B ⁺ ,	1
									0.002			B ⁺	
									-			B ⁺ ,	
									0.001			B ⁺	
16	3d ⁵ -	a ² I - w ² H ^o	2121.26	12300	1	0.047							1
	4p												
17	4s -	a ⁴ H - z	2971.90	12300	1	0.071		0.70				B ⁺	1
	4p	⁴ H ^o	2979.74	12300	1	0.070		0.68	-		0.07	B ⁺ ,	1

			2989.19	12300	1	0.068	0.65	0.004		B ⁺	1
										B ⁺	
18	4s - 4p	a ⁴ H - z ⁴ I ^o	2840.02	12300	1	0.054	0.55	0.00	+/-	B ⁺ ,	1
			2851.35	12300	1	0.056	0.58	1		B ⁺	1
										B ⁺	
19	4s - 4p	a ⁴ H - y ⁴ G ^o	2693.53	12300	1	0.049	0.70	0.00 2	+/-	B ⁺ ,	1
										B ⁺	
20	4s - 4p	a ⁴ H - y ⁴ H ^o	2584.11	12300	1	0.040	0.58			B ⁺	1
21	4s - 4p	a ⁴ F - y ⁴ D ^o	2966.04	12300	1	0.055	0.48	0.00	+/-	B ⁺ ,	1
			3003.92	12300	1	0.062	0.58	2		B ⁺	1
										B ⁺	
22	4s - 4p	a ⁴ F - z ⁴ G ^o	2936.93	12300	1	0.072		0.00 0	-----	B ⁺ ,	1
										B ⁺	
23	4s - 4p	a ⁴ F - x ⁴ D ^o	2727.26	12300	1	0.055				B ⁺	1
24	4s - 4p	b ⁴ G - z ⁴ H ^o	3295.43	12300	1	0.079		- 0.004		B ⁺ ,	1
										B ⁺	
25	4s - 4p	b ⁴ G - z ⁴ G ^o	3122.60	12300	1	0.063		0.00 1		B ⁺ ,	1
										B ⁺	
26	4s - 4p	b ⁴ G - y ⁴ H ^o	2800.77	12300	1	0.064				B ⁺	1
27	4s - 4p	b ⁴ G - ⁴ F ^o	2785.69	12300	1	0.057	0.80			B ⁺	1
			2792.16	12300	1	0.054	0.76	0.00 0	-----	B ⁺ ,	1
										B ⁺	
28	4s - 4p	a ² H - z ⁴ I ^o	3040.92	12300	1	0.080				B ⁺	1
			3050.13	12300	1	0.075		0.01 0		B ⁺ ,	1
										B ⁺	
29	4s - 4p	a ² H - y ² G ^o	2832.45	12300	1	0.062		0.00 9		B ⁺ ,	1
										B ⁺	
30	4s -	a ² P - z ² S ^o	3291.77	12300	1	0.092				B ⁺	1

31	$4p$ $4s -$	$a\ ^2P - z\ ^2P^o$	3172.08	12300	1	0.078	0.85	-	-/+	$B^+,$ B^+	1
32	$4p$ $4s -$	$a\ ^2P - y\ ^4F^o$	3152.22	12300	1	0.072		0.001		$B^+,$ B^+	1
33	$4p$ $4s -$	$b\ ^2F - y\ ^4F^o$	3183.33	12300	1	0.085		0.002		B^+	1
34	$4p$ $4s -$	$b\ ^2F - z\ ^2F^o$	3028.12	12300	1	0.077				B^+	1
35	$4p$ $3d^5 -$	$b\ ^2H - z\ ^2H^o$	3041.72	12300	1	0.092				B^+	1
36	$4p$ $3d^5 -$	$b\ ^2H - ^2I^o$	2575.79	12300	1	0.057				B^+	1
37	$4p$ $3d^5 -$	$b\ ^2H - x\ ^2H^o$	2573.53	12300	1	0.078				B^+	1
38	$4p$ $3d^5 -$	$b\ ^2H - w\ ^2H^o$	2416.40	12300	1	0.062				B^+	1
39	$4p$ $3d^5 -$	$a\ ^2G - v\ ^2F^o$	2215.06	12300	1	0.053				B^+	1
40	$4p$ $4s -$	$c\ ^4D - w\ ^4D^o$	2838.78	12300	1	0.055	0.45	0.00 2	+/-	$B^+,$ B^+	1
41	$4p$ $4s -$	$b\ ^2G - x\ ^4G^o$	3107.57	12300	1	0.079				B^+	1
42	$4p$ $4s -$	$b\ ^2G - x\ ^2G^o$	2927.08	12300	1	0.069				B^+	1
43	$4p$ $4s -$	$c\ ^2G - w\ ^2G^o$	2774.43	12300	1	0.063		0.01 3		$B^+,$ B^+	1
44	$4p$ $3d^5 -$	$c\ ^2F - y\ ^2G^o$	3306.96	12300	1	0.078		0.00 0	-----	$B^+,$ B^+	1
45	$4p$ $4s -$	$b\ ^2D - w\ ^2F^o$	2941.96	12300	1	0.066	0.45	0.00 7	+/-	$B^+,$ B^+	1

The average ratio values	0.50	0.63
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Copper

Cu I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 S_{1/2}$

Ionization energy: 7.726380 eV = 62 317.46 cm⁻¹

Two experiments are devoted to the study of Stark broadening parameters of 22 Cu I lines.^{1,2} For both experiments laser induced plasma is used as a light source. Plasma is observed side-on, Abel inversion carried out, self-absorption tested. Both experiments are carried out with same equipment and by the same group of authors. The experimental details and description of applied plasma diagnostics one can find in Key data on experiments.

The experimental results for Stark widths in table Numerical results for Cu I are compared with SC calculations by Zmerli *et al.*³ (Z). The theoretical calculation, for Stark halfwidths, in this work (TW) was performed correctly only for the first multiplet. For other multiplets the situation is not clear. Namely, the transition energy levels and perturbing levels, in most cases, are mixed. See for example, upper level for the line 2181.72 from multiplet 2: $3d^9(^2D)4s4p(^3P^o)$ $^2P^o$ (65%) and $3d^9(^2D)4s4p(^3P^o)$ $^4D^o$ (33%)⁴. In such cases the calculation is not appropriate.

CR (1990, 02).

References

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³B. Zmerli, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchet, Phys. Scr. **82**, 055301 (2010).

⁴NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	

2165.09	3	3099.93	12	3142.44	11	3282.72	13
2181.72	2	3108.61	11	3146.82	11	3290.54	16
2199.58	7	3116.35	10	3243.16	14	3292.83	4
2199.75	7	3126.11	9	3247.54	1	3307.95	14
2227.78	6	3128.70	12	3273.96	1	3317.22	16
2961.17	5	3140.31	8	3279.82	5	3319.68	15

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 532 nm Single pulse 6 mJ, 5 ns, repetition rate 1 Hz Target: pure copper at pressure of 8 Pa	Saha equation using Cu I and Cu II lines	Boltzmann plot of Cu II lines	Plasma observed side-on
2	Nd:YAG laser at 532 nm Single pulse 6 mJ, 5 ns, repetition rate 1 Hz Target: pure copper at pressure of 8 Pa	Saha equation using Cu I and Cu II lines	Boltzmann plot of Cu I and Cu II spectral lines	Plasma observed side-on

Numerical results for Cu I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_z	w_m/w_{TW}	Acc.	Ref.
1	$4s - 4p$	$^2S - ^2P^o$	3247.54	19300	2.1	0.125	1.75	0.81	B ⁺	2
			3273.96	19300	2.1	0.119	1.72	0.79	B ⁺	2
2	$4s - 4p(^3P^o)$	$^2S - ^2P^o$	2181.72	18400	0.63	0.094			C ⁺	1
3	$4s - 4p(^3P^o)$	$^2S - ^o$	2165.09	18400	0.63	0.074			C ⁺	1
4	$4s^2 - 4p(^3P^o)$	$^2D - ^4F^o$	3292.83	18400	0.63	0.112			C ⁺	1
5	$4s^2 - 4p(^3P^o)$	$^2D - ^2F^o$	2961.17	18400	0.63	0.085			C ⁺	1
			3279.82	18400	0.63	7			C ⁺	1
						0.097				
6	$4s^2 - 4p(^1P^o)$	$^2D - ^2F^o$	2227.78	18400	0.63	0.164			B	1
7	$4s^2 - 4p(^1P^o)$	$^2D - ^2D^o$	2199.58	18400	0.63	0.129			B	1
			2199.75	18400	0.63	9			B	1
						0.117				
8	$4p(^3P^o) -$ $(^3D)4d$	$^4P^o - ^2P$	3140.31	18400	0.63	0.151			C ⁺	1
9	$4p(^3P^o) -$ $(^3D)4d$	$^4P^o - ^4S$	3126.11	18400	0.63	0.144			C ⁺	1
10	$4p(^3P^o) -$ $(^3D)4d$	$^4P^o - ^2D$	3116.35	18400	0.63	0.169			C ⁺	1
11	$4p(^3P^o) -$ $(^3D)4d$	$^4P^o - ^4P$	3108.61	18400	0.63	0.191			B	1
			3142.44	18400	0.63	9			C ⁺	1
			3146.82	18400	0.63	0.196			C ⁺	1
						4				
						0.169				
						7				
12	$4p(^3P^o) -$ $(^3D)4d$	$^4P^o - ^4D$	3099.93	18400	0.63	0.145			C ⁺	1
			3128.70	18400	0.63	9			C ⁺	1
						0.143				
						7				
13	$4p(^3P^o) -$ $(^3D)4d$	$^4F^o - ^2G$	3282.72	18400	0.63	0.182			B	1
14	$4p(^3P^o) -$ $(^3D)4d$	$^4F^o - ^4G$	3243.16	18400	0.63	0.197			B	1
			3227.25	18400	0.63	5			B	1

Copper

Cu II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} \ ^1S_0$

Ionization energy: 20.29239 eV = 163 669.2 cm⁻¹

The experimental details and plasma diagnostic procedures of side-on observed laser induced plasma are described in Ref. 1. The procedure of measurements Stark broadening parameters of Cu II lines include Abel inversion, see also Cu I report. Another experimental approach² for the study of Cu II lines with end-on plasma observation is described in Ref. 2, see also report for Ca I.

The self-absorption test for studied Stark broadened Cu II lines are applied in both experiments.^{1,2} The optically thin Cu II lines are used only for Stark broadening parameters derivation.

The only available SC theoretical data are evaluated in this work (TW) and used for comparison with the measured Cu II Stark parameters. The comparison theory with experiment is omitted for multiplets M11, M18, M25 and M53 because of involvement two-electron transitions while in other cases the omission occurs because of problems caused with incompleteness of perturbing levels in NIST Database.³

It should be noticed in addition, that in multiplets M1, M2, M5, M20, M23, M40 and M43 there is always one experimental Stark halfwidth, in each multiplet, which is lower than the rest of halfwidths and which belongs to Ref. 1. Analysis of the corresponding sets of perturbing levels from Ref. 3 does not support this discrepancy.

The temperature value of 11000 K, given in the Numerical table for Ref. 2, is derived from graphical presentation of plasma diagnostic data.

CR (1990, 02).

References

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- ³NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.
1979.96	5	2130.08	21	2294.37	1	2713.51	30
1989.85	5	2134.34	21	2336.17	47	2718.78	45
1999.70	5	2135.98	2	2348.73	37	2721.68	36
2015.58	6	2145.49	14	2355.01	13	2745.27	35
2016.90	4	2146.92	43	2356.64	1	2769.67	35
2025.49	5	2148.98	2	2369.89	8	2837.37	35
2027.13	17	2151.81	23	2376.30	46	2857.75	35
2029.95	15	2161.32	34	2400.11	7	2877.70	44
2031.04	15	2174.98	41	2403.34	12	2884.20	35
2035.85	5	2189.63	9	2424.43	13	3686.56	18
2037.13	5	2195.68	29	2468.50	20	4043.49	25
2043.80	3	2200.51	43	2473.33	12	4555.92	11
2054.98	4	2212.75	43	2485.79	20	4758.43	11
2062.42	16	2215.11	43	2489.65	7	4812.95	54
2066.26	17	2226.78	33	2506.27	19	4851.26	51
2078.66	14	2230.95	42	2526.59	19	4854.99	51
2085.30	2	2231.58	28	2529.30	27	4909.73	50
2087.92	24	2248.97	39	2544.81	19	4918.38	55
2093.64	15	2254.99	49	2571.76	31	4931.70	50
2098.40	23	2263.21	32	2590.53	31	4953.72	55
2104.80	4	2263.79	38	2598.81	19	4985.50	52
2111.29	22	2265.36	40	2600.27	36	5006.80	56
2112.10	10	2276.26	1	2666.29	26	5124.47	53
2117.31	21	2278.34	40	2689.30	26		
2122.98	9	2286.64	37	2700.96	36		
2126.04	2	2291.00	48	2703.18	36		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 532 nm Single pulse 6 mJ, 5 ns, repetition rate 1 Hz Target: pure copper at the pressure of 8 Pa	Saha equation using Cu I and Cu II lines	Boltzmann plot of Cu II lines	Plasma observed side-on
2	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet made of hydrate calcium sulfate powder positioned in chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Cu II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	4s - 4p	$^3D - ^3P^\circ$	2276.26	19300	2.1	0.1242	1.19			B	1
			2294.37	19300	2.1	0.1386	1.35			B	1

			2356.64	19300	2.1	0.0878	0.81			C ⁺	1
2	4s - 4p	³ D - ³ F°	2085.30	19300	2.1	0.0954	2.03			B	1
			2126.04	19300	2.1	0.1782	3.31			B	1
				11000	1	0.0600	1.85	0.011	+/-	C ⁺	2
			2135.98	11000	1	0.0600	1.54	0.011	+/-	C ⁺	2
			2148.98	19300	2.1	0.1440	2.72			B	1
3	4s - 4p	³ D - ¹ F°	2043.80	19300	2.1	0.1692	2.48			B	1
4	4s - 4p	³ D - ¹ D°	2016.90	19300	2.1	0.1692	2.63			B	1
			2054.98	19300	2.1	0.1728	2.47			B	1
			2104.80	19300	2.1	0.1386	1.89			B	1
5	4s - 4p	³ D - ³ D°	1979.96	19300	2.1	0.1764	3.60			B	1
			1989.85	19300	2.1	0.1854	3.79			B	1
			1999.70	19300	2.1	0.1980	3.84			B	1
			2025.49	19300	2.1	0.1242	2.37			B	1
			2035.85	19300	2.1	0.1764	3.06			B	1
			2037.13	19300	2.1	0.1782	3.31			B	1
6	4s - 4p	³ D - ¹ P°	2015.58	19300	2.1	0.2124	3.25			B	1
7	4s - 4p	¹ D - ³ P°	2400.11	19300	2.1	0.0882	0.94			C ⁺	1
			2489.65	19300	2.1	0.0880	0.87			C ⁺	1
8	4s - 4p	¹ D - ³ F°	2369.89	19300	2.1	0.1530	1.63			B	1
9	4s - 4p	¹ D - ³ D°	2122.98	19300	2.1	0.1854	2.43			B	1
			2189.63	19300	2.1	0.1674	2.08			B	1
10	4s - 4p	¹ D - ¹ P°	2112.10	19300	2.1	0.1710	1.95			B	1
11	4p - 4s ²	³ P° - ³ P	4555.92	19300	2.1	0.1980				C ⁺	1
			4758.43	19300	2.1	0.1908				C ⁺	1
12	4p - (² D _{5/2})5s	³ P° - ² [5/2]	2403.34	19300	2.1	0.1962				B	1
			2473.33	19300	2.1	0.1764				B	1
13	4p - (² D _{3/2})5s	³ P° - ² [3/2]	2355.01	19300	2.1	0.1836				B	1
			2424.43	19300	2.1	0.1764				C ⁺	1
14	4p - (² D _{5/2})4d	³ P° - ² [1/2]	2078.66	19300	2.1	0.1404	0.77			B	1
			2145.49	19300	2.1	0.1134	0.58			B	1

15	$4p - (^2D_{5/2})4d$	$^3P^\circ - ^2[3/2]$	2029.95	19300	2.1	0.1386	0.59	B	1
			2031.04	19300	2.1	0.1656	0.71	B	1
			2093.64	19300	2.1	0.1620	0.65	B	1
16	$4p - (^2D_{5/2})4d$	$^3P^\circ - ^2[5/2]$	2062.42	19300	2.1	0.1962		B	1
17	$4p - (^2D_{3/2})4d$	$^3P^\circ - ^2[1/2]$	2027.13	19300	2.1	0.1170	0.56	B	1
			2066.26	19300	2.1	0.1332	0.62	C ⁺	1
18	$4p - 4s^2$	$^3F^\circ - ^1G$	3686.56	19300	2.1	0.1206		C ⁺	1
19	$4p - (^2D_{5/2})5s$	$^3F^\circ - ^2[5/2]$	2506.27	19300	2.1	0.2088		B	1
			2526.59	19300	2.1	0.2052		B	1
			2544.81	19300	2.1	0.2160		B	1
			2598.81	19300	2.1	0.2232		B	1
20	$4p - (^2D_{3/2})5s$	$^3F^\circ - ^2[3/2]$	2468.50	19300	2.1	0.1080		C ⁺	1
			2485.79	19300	2.1	0.1926		B	1
21	$4p - (^2D_{5/2})4d$	$^3F^\circ - ^2[9/2]$	2117.31	19300	2.1	0.1836	0.82	B	1
			2130.08	19300	2.1	0.1548	0.67	B	1
			2134.34	19300	2.1	0.1980	0.88	B	1
22	$4p - (^2D_{5/2})4d$	$^3F^\circ - ^2[5/2]$	2111.29	19300	2.1	0.1962		B	1
23	$4p - (^2D_{5/2})4d$	$^3F^\circ - ^2[7/2]$	2098.40	19300	2.1	0.2160	0.82	B	1
			2151.81	19300	2.1	0.1512	0.55	B	1
24	$4p - (^2D_{3/2})4d$	$^3F^\circ - ^2[7/2]$	2087.92	19300	2.1	0.1836	0.86	B	1
25	$4p - 4s^2$	$^1F^\circ - ^1G$	4043.49	19300	2.1	0.1350		C ⁺	1
26	$4p - (^2D_{5/2})5s$	$^1F^\circ - ^2[5/2]$	2666.29	19300	2.1	0.1836		B	1
			2689.30	19300	2.1	0.2106		B	1
27	$4p - (^2D_{3/2})5s$	$^1F^\circ - ^2[3/2]$	2529.30	19300	2.1	0.2070		B	1
28	$4p - (^2D_{5/2})4d$	$^1F^\circ - ^2[3/2]$	2231.58	19300	2.1	0.2286	0.81	B	1
29	$4p - (^2D_{5/2})4d$	$^1F^\circ - ^2[7/2]$	2195.68	19300	2.1	0.1782	0.62	B	1
30	$4p - (^2D_{5/2})5s$	$^1D^\circ - ^2[5/2]$	2713.51	19300	2.1	0.2124		B	1
31	$4p - (^2D_{3/2})5s$	$^1D^\circ - ^2[3/2]$	2571.76	19300	2.1	0.1980		C ⁺	1
			2590.53	19300	2.1	0.1962		B	1
32	$4p - (^2D_{5/2})4d$	$^1D^\circ - ^2[3/2]$	2263.21	19300	2.1	0.1908	0.65	B	1
33	$4p - (^2D_{5/2})4d$	$^1D^\circ - ^2[5/2]$	2226.78	19300	2.1	0.2268		B	1

34	$4p - (^2D_{3/2})4d$	$^1D^\circ - ^2[7/2]$	2161.32	19300	2.1	0.1476	0.65	B	1
35	$4p - (^2D_{5/2})5s$	$^3D^\circ - ^2[5/2]$	2745.27	19300	2.1	0.2250		C ⁺	1
			2769.67	19300	2.1	0.2214		C ⁺	1
			2837.37	19300	2.1	0.1998		B	1
			2857.75	19300	2.1	0.1944		C ⁺	1
			2884.20	19300	2.1	0.2142		C ⁺	1
36	$4p - (^2D_{3/2})5s$	$^3D^\circ - ^2[3/2]$	2600.27	19300	2.1	0.2070		B	1
			2700.96	19300	2.1	0.2466		B	1
			2703.18	19300	2.1	0.2520		B	1
			2721.68	19300	2.1	0.2034		B	1
37	$4p - (^2D_{5/2})4d$	$^3D^\circ - ^2[3/2]$	2286.65	19300	2.1	0.1764	0.60	B	1
			2348.73	19300	2.1	0.1782	0.57	B	1
38	$4p - (^2D_{5/2})4d$	$^3D^\circ - ^2[5/2]$	2263.79	19300	2.1	0.1710		B	1
39	$4p - (^2D_{5/2})4d$	$^3D^\circ - ^2[7/2]$	2248.97	19300	2.1	0.2394	0.79	B	1
40	$4p - (^2D_{3/2})4d$	$^3D^\circ - ^2[1/2]$	2265.36	19300	2.1	0.1368	0.53	C ⁺	1
			2278.34	19300	2.1	0.1944	0.74	B	1
41	$4p - (^2D_{3/2})4d$	$^3D^\circ - ^2[7/2]$	2174.98	19300	2.1	0.1674	0.72	B	1
42	$4p - (^2D_{3/2})4d$	$^3D^\circ - ^2[3/2]$	2230.95	19300	2.1	0.2070	0.73	B	1
43	$4p - (^2D_{3/2})4d$	$^3D^\circ - ^2[5/2]$	2146.92	19300	2.1	0.1296	0.48	B	1
			2200.51	19300	2.1	0.1602	0.56	B	1
			2212.75	19300	2.1	0.1584	0.54	B	1
			2215.11	19300	2.1	0.1926	0.67	B	1
44	$4p - (^2D_{5/2})5s$	$^1P^\circ - ^2[5/2]$	2877.70	19300	2.1	0.2124		B	1
45	$4p - (^2D_{3/2})5s$	$^1P^\circ - ^2[3/2]$	2718.78	19300	2.1	0.2142		B	1
46	$4p - (^2D_{5/2})4d$	$^1P^\circ - ^2[3/2]$	2376.30	19300	2.1	0.1908	0.59	B	1
47	$4p - (^2D_{5/2})4d$	$^1P^\circ - ^2[5/2]$	2336.17	19300	2.1	0.2214		B	1
48	$4p - (^2D_{3/2})4d$	$^1P^\circ - ^2[1/2]$	2291.00	19300	2.1	0.1800	0.68	B	1
49	$4p - (^2D_{3/2})4d$	$^1P^\circ - ^2[3/2]$	2254.99	19300	2.1	0.1530	0.57	B	1
50	$(^2D_{5/2})4d - (^2D_{5/2})4f$	$^2[9/2] -$	4909.73	19300	2.1	1.0080		B	1
		$^2[11/2]^\circ$	4931.70	19300	2.1	0.9000		B	1
51	$(^2D_{5/2})4d - (^2D_{5/2})4f$	$^2[9/2] -$	4851.26	19300	2.1	1.1088		B	1

		$^2[9/2]^\circ$	4854.99	19300	2.1	1.1826		B	1
52	$(^2D_{5/2})4d - (^2D_{5/2})4f$	$^2[5/2] -$	4985.50	19300	2.1	1.1556		B	1
		$^2[7/2]^\circ$							
53	$(^2D_{5/2})4d - 4p(^1P^\circ)$	$^2[7/2] - ^3G^\circ$	5124.47	19300	2.1	1.0386		B	1
54	$(^2D_{3/2})4d - (^2D_{3/2})4f$	$^2[1/2] -$	4812.95	19300	2.1	0.9144	0.10	B	1
		$^2[3/2]^\circ$							
55	$(^2D_{3/2})4d - (^2D_{3/2})4f$	$^2[7/2] -$	4918.38	19300	2.1	0.8928	0.21	B	1
		$^2[9/2]^\circ$	4953.72	19300	2.1	1.0008	0.23	B	1
56	$(^2D_{3/2})4d - (^2D_{3/2})4f$	$^2[3/2] -$	5006.80	19300	2.1	1.1736	0.15	B	1
		$^2[5/2]^\circ$							
The average ratio values						1.31			

Germanium

Ge I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2 \ ^3P_0$

Ionization energy: 7.899435 eV = 63 713.24 cm⁻¹

Single experiment deals with Stark broadening of neutral germanium spectral lines.¹ Pulsed Nd: YAG laser is used to induce plasma at the surface of Ge target at atmospheric pressure. Five handheld spectrometers with CCD detectors were used simultaneously to cover wavelength region from 2497.963 Å until 4685.829 Å. For experimental details see the table Key data on experiment.

The experimental results are compared with SC theoretical calculations of Ref. 2 (DJ) and with data calculated within this work (TW). The differences between experimental and theoretical results are exceedingly large, see table of Numerical results for Ge I and therefore further discussion is interrupted especially after intercomparisons of Ge II results, see the Numerical results for Ge II where reasonable agreement between theory and experiment is evident. This is the reason also why accuracy is not estimated.

CR (1976, 84, 90)

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Finding list

Wavelengt h (Å)	No.	Wavelengt h (C)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2497.96	2	2651.17	1	2754.59	1	4226.56	6
2533.23	2	2651.57	1	3039.07	4	4685.83	5
2589.19	2	2691.34	1	3124.82	3		
2592.53	1	2709.62	1	3269.49	3		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm Pulse energy 400 mJ, with 5 ns and repetition rate of 10 Hz Target: germanium sample Plasma is generated in air at atmospheric pressure	H $_{\alpha}$ Stark halfwidth	Boltzmann plot of six Ge I spectral lines	Plasma observed side-on Abel inversion is not performed

Numerical results for Ge I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m /w _{DJ}	w _m / w _{TW}	Acc.	Ref.
1	4p ² - 5s	³ P - ³ P ^o	2592.53	10500	0.84	1.04	14.90	10.60		1
			2651.17	10500	0.84	1.47	20.16	17.05		1
			2651.57	10500	0.84	1.47	22.29	17.05		1
			2691.34	10500	0.84	0.82	12.08	9.12		1
			2709.62	10500	0.84	1.12	16.12	12.11		1
			2754.59	10500	0.84	1.12	15.76	11.90		1
2	4p ² - 5s	³ P - ¹ P ^o	2497.96	10500	0.84	0.82		8.82		1
			2533.23	10500	0.84	0.83		8.68		1
			2589.19	10500	0.84	0.68		6.80		1
3	4p ² - 5s	¹ D - ³ P ^o	3124.82	10500	0.84	1.33	13.19	9.27		1
			3269.49	10500	0.84	1.04	10.40	7.82		1
4	4p ² - 5s	¹ D - ¹ P ^o	3039.07	10500	0.84	1.02	9.95	7.49		1
5	4p ² - 5s	¹ S - ³ P ^o	4685.83	10500	0.84	1.30	6.37	4.81		1
6	4p ² - 5s	¹ S - ¹ P ^o	4226.56	10500	0.84	0.85	4.31	3.24		1
The average ratio values							13.23	9.63		

Germanium

Ge II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2 P^{\circ}_{1/2}$

Ionization energy: $15.934610 \text{ eV} = 128\,521.3 \text{ cm}^{-1}$

Stark broadening parameters of Ge II lines are reported in two experiments^{1,2}. First experiment describes experimental details of Ge II spectral lines measured and the experimental procedure which is identical with the one described in Ref.1 in relation with Ge I. It is basically the same experimental study published in Ref.1. The second paper by Dojić et al.² is typical laser 532 nm plasma experiment induced at the surface of germanium target at atmospheric pressure. The H_{α} Stark halfwidth was used to determine electron density and Boltzmann plot of Ge I spectral lines for determination of electron temperature.

The comparison of experimental and SC theoretical results are performed only with theoretical results calculated in this work (TW).

CR (1976).

References

¹J. Iqbal, R. Ahmed, M. A. Baig, Laser Phys. **27**, 046101 (2017).

²D. Dojić, M. Skočić, S. Bukvić, S. Djeniže, Month. Not. Roy. Astron. Soc. **484**, 3419 (2019).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2831.84	3	4814.61	5	5893.39	1	6966.32	2
2845.48	3	4824.10	5	6021.04	1	7049.37	2
3499.21	6	5131.75	7	6336.38	4	7145.39	2
4741.81	5	5178.65	7	6484.18	4		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm Pulse energy 400 mJ, with 5 ns and repetition rate of 10 Hz Target: germanium sample Plasma generated in air at atmospheric pressure	H α Stark halfwidth	Boltzmann plot of Ge I spectral lines	Plasma observed side-on No Abel inversion performed
2	Nd:YAG laser at 532 nm Pulse with 5 ns and repetition rate of 1 Hz. Target: germanium sample Plasma generated in helium atmosphere with pressure in the range 0.1-200 mbar	Peak separation of He I 4471.48 Å line	Boltzmann plot of Ge I and Ge II spectral lines	Plasma observed side-on

Numerical results for Ge II

No .	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	$4s^25s - 4s^25p$	$^2S - ^2P^o$	5893.39	10500	0.84	3.50	1.83			B	1
				12000	1	1.65	0.77	0.205	0.25	B^+ ,	2
			6021.04	10500	0.84	2.97	1.57			B^+	1
				12000	1	1.80	0.85	0.253	0.29	B	2
										B^+, B	
2	$4s4p^2 - 4s^25p$	$^2D - ^2P^o$	6966.32	10500	0.84	4.51	1.67			B	1
			7049.37	10500	0.84	4.37	1.58			B	1
			7145.39	10500	0.84	3.51	1.31			B	1
3	$4s4p^2 - 4s^24f$	$^2D - ^2F^o$	2831.84	12000	1	1.12	0.91	- 0.086	0.22	B^+, B	2
			2845.48	12000	1	1.13	0.89	- 0.070	0.17	B^+, C	2
4	$4s^25p - 4s^26s$	$^2P^o - ^2S$	6336.38	10500	0.84	4.33	1.58			B	1
				12000	1	3.12	0.98	> 0.23		B^+	2
			6484.18	10500	0.84	5.51	1.87			B	1
5	$4s^25p - 4s^25d$	$^2P^o - ^2D$	4741.81	10500	0.84	5.97	1.32			B	1
				12000	1	5.61	1.09	1.262	0.69	B^+ ,	2
			4814.61	10500	0.84	7.45	1.52			B^+	1
				12000	1	5.54	0.99	1.310	0.68	B	2
			4824.10	12000	1	6.47	1.21	> 0.26		B^+ ,	2
										B^+	
										B^+	
6	$4s^25p - 4s^27s$	$^2P^o - ^2S$	3499.21	12000	1	2.16	1.07	> 0.14		B^+	2
7	$4s^24d - 4s^24f$	$^2D - ^2F^o$	5131.75	10500	0.84	4.25	1.14			B	1
				12000	1	3.95	0.95	- 0.289	0.25	B^+ ,	2
			5178.65	10500	0.84	4.63	1.19			B^+	1
				12000	1	4.00	0.92	- 0.290	0.24	B	2
										B^+ ,	
										B^+	
The average ratio values							1.24		0.35		

Gold

Au I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^{10} 6s^2 S_{1/2}$

Ionization energy: 9.225554 eV = 74 409.11 cm⁻¹

Low pressure pulsed arc in glass tube internal diameter 5 mm and plasma length 14 cm is used as a plasma source in this study of Au I lines. The brass electrodes are in expanded part at both end of discharge tube, see Fig.1 in Ref. 1. The gold atoms are evaporated from gold cylindrical plates placed axially inside of narrow part of glass tube. Pulsed plasma is generated by repetitively discharging. The used spectroscopic equipment and line shape recording technique with photomultiplier is the same as described in Ref.1 for Ar III, see also Key data on experiment. The transition arrays and in one case (Multiplet 2) are corrected in agreement with NIST data tables,² see Numerical results for Au I.

The only SC results used for comparison with experiment are calculated within this work (TW). The average ratio of measured over theoretical results is not given because of large variations of the ratios for studied lines. The $\Delta S/S$ in the case of w_m/w_{TW} ratio (3.31) for the 4040.93 Å line from multiplet M2 is -0.569, close to the limit of $\Delta S/S = -0.6$.

References

¹S. Djeniže, Spectrochim. Acta B **64**, 242 (2009).

²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
4040.93	2	4792.58	3	6278.17	1		
4065.07	3	4811.60	3				

Key data on experiment

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc in glass tube operated in gas mixture of 90% He + 7% N ₂ + 3% O ₂ at the pressure of 665 Pa	Stark halfwidth of He II P α line	Relative intensity of O II and O III spectral lines	Plasma observed end-on

Numerical results for Au I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_{TW}	Acc.	Ref.
1	5d ⁹ 6s ² – 5d ¹⁰ 6p	² D – ² P ^o	6278.17	16300	0.70	0.162	1.16	C ⁺	1
2	5d ⁹ 6s ² – 5d ⁹ 6s6p	² D – ⁴ F ^o	4040.93	16300	0.70	0.090	3.31	C ⁺	1
3	5d ¹⁰ 6p – 5d ¹⁰ 6d	² P ^o – ² D	4065.07	16400	0.71	0.160	0.19	C ⁺	1
			4792.58	16400	0.71	0.140	0.12	C ⁺	1
			4811.60	16400	0.71	0.150	0.13	C ⁺	1

Gold

Au II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^9 \ ^1S_0$

Ionization energy: 20.203 eV = 162 950 cm⁻¹

The details of experimental setup and experimental procedure of Au II line shape recording, one can find in the Au I report. Namely, the Stark broadening parameters for lines of neutral atoms and singly charged ions of gold are reported in Ref. 1. The transition arrays, multiplets and wavelengths of Au II lines in Numerical results for Au II are given in accordance with Ref. 2. Only several of these lines one can find in NIST data tables.³ Due to the lack of energy level data and transition probabilities the semiclassical calculations of Stark parameters are performed in a few cases only. Besides this and $\Delta S/S = -0.94$ for the 2822.55 Å line in multiplet M4, the value of the w_m/w_{TW} parameter is not given. All these are the reason why the average ratio measured over calculated halfwidth values was not introduced in Numerical results for Au II.

More Au II experimental data one can find in earlier critical review CR (2009).

References

¹S. Djeniže, Spectrochim. Acta B **64**, 242 (2009).

²M. Rosberg, J-F. Wyart, Phys. Scripta **55**, 690 (1997)

³NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2213.16	1	2314.55	5	2837.85	4	2994.80	4
2231.21	5	2315.75	4	2846.92	4	3706.55	4
2240.18	5	2340.08	5	2856.74	4	3804.01	2
2248.56	4	2802.04	4	2907.04	3	4016.07	2
2283.31	1	2819.79	4	2913.52	3	4052.79	2
2291.41	4	2822.55	4	2918.24	4		

2304.68	5	2825.44	1	2954.22	4
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Key data on experiments

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc running in gas mixture 90% He + 7% N ₂ + 3% O ₂ at the pressure of 665 Pa	Stark halfwidth of the He II P α spectral line	Relative intensity of O II and O III spectral lines	Plasma observed end-on

Numerical results for Au II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m /w _{TW}	Acc.	Ref.
1	5d ⁹ 6s - 5d ⁹ 6p	(3/2, 1/2) ₂ - (5/2, 3/2) ^o ₃	2213.16	16800	0.78	0.125		B	1
		(3/2, 1/2) ₂ - (5/2, 3/2) ^o ₁	2283.31	16800	0.78	0.120		B	1
		(3/2, 1/2) ₂ - (5/2, 3/2) ^o ₁	2825.44	16800	0.78	0.118		B	1
2	5d ⁸ 6s ² - 5d ⁸ 6p	³ P ₂ - (5/2, 3/2) ^o ₃	3804.01	16600	0.74	0.128		B	1
		³ P ₂ - (5/2, 3/2) ^o ₁	4016.07	16300	0.70	0.121		B	1
		³ P ₂ - (5/2, 3/2) ^o ₂	4052.79	16600	0.76	0.160		B	1
3	5d ⁸ 6s ² - 5d ⁸ 6p	³ F ₃ - (3/2, 3/2) ^o ₂	2907.04	16600	0.74	0.154		B	1
		³ F ₄ - (5/2, 3/2) ^o ₃	2913.52	16600	0.76	0.154		B	1
4	5d ⁹ 6p - 5d ⁹ 7s	(3/2, 1/2) ^o ₂ - (3/2, 1/2) ₂	2248.56	16800	0.78	0.088		B	1
		(5/2, 1/2) ^o ₃ - (5/2, 1/2) ₂	2291.41	16800	0.78	0.092		B	1
		(5/2, 1/2) ^o ₃ - (5/2, 1/2) ₂	2315.75	16900	0.76	0.102		B	1
		(5/2, 1/2) ^o ₃ - (5/2, 1/2) ₃	2802.04*	16600	0.76	0.121	0.89	B	1
		(5/2, 3/2) ^o ₄ - (5/2, 1/2) ₃	2819.79	16600	0.76	0.166		B	1
		(5/2, 3/2) ^o ₂ - (5/2, 1/2) ₂	2822.55*	16800	0.78	0.158		B	1
		(5/2, 3/2) ^o ₂ - (5/2, 1/2) ₂	2837.85	16600	0.76	0.100		B	1
		(3/2, 3/2) ^o ₃ - (3/2, 1/2) ₂	2846.92	16900	0.76	0.114		B	1
		(5/2, 3/2) ^o ₃ - (5/2, 1/2) ₂	2856.74	16600	0.74	0.120		B	1
		(5/2, 3/2) ^o ₃ - (5/2, 1/2) ₂	2918.24*	16600	0.74	0.154	1.98	B	1
		(5/2, 3/2) ^o ₁ - (5/2, 1/2) ₂	2954.22	16600	0.74	0.132		B	1
		(5/2, 3/2) ^o ₁ - (5/2, 1/2) ₂	2994.80*	16600	0.74	0.156	1.03	B	1
		(3/2, 3/2) ^o ₁ - (3/2, 1/2) ₁	3706.55	16400	0.71	0.170		B	1
		(5/2, 3/2) ^o ₂ - (5/2, 1/2) ₃							
		(3/2, 3/2) ^o ₂ - (3/2, 1/2) ₁							
		(5/2, 3/2) ^o ₃ - (5/2, 1/2) ₂							
		(5/2, 3/2) ^o ₃ - (5/2, 1/2) ₃							
		(3/2, 1/2) ^o ₁ - (5/2, 1/2) ₂							

The lines for which Transition array and Multiplet notation can be find in NIST data tables.³

Helium

He I

Ground state: $1s^2\ ^1S_0$

Ionization energy: 24.587389011 eV = 198 310.66637 cm⁻¹

Two extensive papers^{1,2} describe experimental studies of the Stark broadening of neutral helium lines as well as paper.³ First one reports experiment¹ carried out in an electromagnetically driven T-tube at initial pressure of 500 Pa of pure helium while the second one² is performed in linear low-pressure pulsed co-axial discharge filled with helium-hydrogen (97 % + 3 %) gas mixture at an initial pressure of 200 mbar. Before starting with He I spectral line shape recordings all precautions are taken to check whether spectral lines are optically thin and whether instrumental line profile is recorded to enable correct deconvolution of recorded experimental line profiles. Plasma electron density in both cases^{1,2} is determined from the wavelength separation of allowed and forbidden component of He I 4471 Å line while electron temperatures are determined from the Boltzmann plot of Si II spectral lines present in discharges as a result of glass wall ablation. In the experiment with T-tube¹ plasma is observed side-on while in linear discharge² plasma is observed along the axis of discharge tube. All details about used plasma sources, and plasma diagnostics, one can find in table Key data on experiments.

In Ref. 3 is reported Stark broadened halfwidth of He I 3889 Å line observed in laser produced plasma. Abel inversion procedure is performed, and self-absorption tested in order to determine optically thin conditions suitable for line halfwidth measurements.

The experimental and SC results used for comparison one can find in the table Numerical results for He I. The results in this table for He I are presented in similar way as for most preceding data. The exceptions are as follows:

- Experimental data for He I 4471 Å line are excluded from the table (line with allowed and forbidden component). However, the wavelength separations between these two 4471 Å line components and their ratios of intensities are successfully used for electron density measurements.^{1,2}

- The experimental shifts given in Numerical result for He I are measured at the peak of the He I spectral lines except for four shifts

measured at the line halfwidth and these values are marked by the asterisk.

- In the case, of evaluation of ion broadening contribution to the total He I halfwidth and shift we used proposed procedure from Ref. 4 (G), Ref. 5 (DSB) and this work (TW).

CR (1976, 84, 90, 02, 09).

References

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²T. Gajo, M. Ivković, N. Konjević, I. Savić, S. Djurović, Z. Mijatović, R. Kobilarov, *Month.*

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⁴H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).

⁵M. S. Dimitrijević, S. Sahal-Brechot, *Astron. Astrophys. Suppl. Ser.* **82**, 519 (1990).

Finding list

Waveleng th (Å)	No.	Waveleng th (Å)	No.	Waveleng th (Å)	No.	Waveleng th (Å)	No.
3889.65	1	5015.68	2	7065.19	3		
4713.15	4	6678.15	6	7281.35	5		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Electromagnetically driven T-Tube filled with pure helium at the initial pressure of 500 Pa	Wavelength separation between the peaks of the allowed and forbidden components of He I 4471 Å spectral line	Boltzmann plot of eight Si II spectral lines	Plasma observed side-on
2	Linear pulsed discharge with helium + 3% of hydrogen gas mixture at the initial pressure of 200 mbar	Wavelength separation between the peaks of the allowed and forbidden components of He I 4471 Å spectral line	Boltzmann plot of seven Si II spectral lines	Plasma observed end-on
3	Nd:YAG laser, EKSPLA NL311-SH-TH, at 532 nm, 200 mJ, 5ns. Repetition 1 Hz Target: aluminum sample (purity 99%) The experiment was conducted in helium-hydrogen gas mixture (92% He, 8% H ₂) under pressure of 300 mbar	H _β Stark halfwidth	Boltzmann plot of six Al II and eight Al III spectral lines	Plasma observed side-on

														B ⁺		
														B ⁺ , B ⁺		
2	2 <i>s</i> - 3 <i>p</i>	¹ S - ¹ P ^o	5015.68	14600	0.615						- 1.9	1.05	0.93	0.95		2
				16000	0.87					- 2.2	0.86	0.78	0.76	B ⁺	2	
				16900	2.34	15.23	0.72	0.84	0.63	-	0.54	0.68	0.46		1	
										5.06*	0.54	0.52	0.47	B ⁺	1	
				17000	1.28					- 3.90	0.76	0.71	0.67	B ⁺ ,	2	
				18100	1.48					- 2.9	0.75	0.71	0.65	B	2	
				19000	1.91					- 3.3	0.84	0.80	0.72		2	
				19000	4.85					- 4.8	0.74	0.76	0.63	B	2	
				19500	2.54					-11.5	0.77	0.76	0.66		2	
				20000	5.60					- 6.0	0.65	0.68	0.55	B ⁺	2	
				20000	7.00					- 11.7	0.59	0.63	0.50		2	
				20200	3.72					- 13.6	0.70	0.71	0.59	B ⁺	2	
										- 8.1						
														B ⁺		
														B ⁺		
										B ⁺						
										B ⁺						
										B ⁺						
3	2 <i>p</i> - 3 <i>s</i>	³ P ^o - ³ S	7065.19	14600	0.615						1.5	0.97	0.76	0.89		2
				16000	0.87					2.9	1.31	1.04	1.22	B ⁺	2	
				16900	2.34	11.65	0.98	1.16	0.88		0.87	0.76	0.80		1	
										5.72*	0.87	0.71	0.81	B	1	

														B ⁺	
														B ⁺	
														B ⁺	
														B ⁺	
5	2p – 3s	¹ P ^o – ¹ S	7281.35	14600	0.615					2.8	1.07	0.86	1.01		2
				16000	0.87					4.8	1.30	1.05	1.23	B ⁺	2
				17000	1.28					5.7	1.04	0.85	0.98		2
				18100	1.48					7.5	1.18	0.97	1.12	B ⁺	2
				19000	1.91					9.2	1.12	0.92	1.06		2
				19000	4.85					21.3	1.00	0.84	0.94	B ⁺	2
				19500	2.54					16	1.46	1.21	1.37		2
				20000	5.60					24.0	0.98	0.83	0.91	B ⁺	2
				20200	3.72					15.9	0.99	0.82	0.92		2
														B ⁺	
														B ⁺	
														B ⁺	
6	2p – 3d	¹ P ^o – ¹ D	6678.15	14600	0.615					1.7	0.83	0.63	0.70		2
				16000	0.87					2.9	0.99	0.76	0.83	C ⁺	2
				16900	2.34	18.50	0.83	0.89	0.73		0.42	0.43	0.34		1
										4.39*	0.39	0.32	0.32	B	1
				17000	1.28					3.24	0.75	0.59	0.63	B ⁺ ,	2
				18100	1.48					3.3	0.82	0.66	0.68	B	2

19000	1.91	4.2	0.79	0.65	0.66		2
19000	4.85	5.3	0.64	0.55	0.53	B	2
19500	2.54	11.5	0.75	0.62	0.62		2
20000	5.60	6.8	0.54	0.48	0.45	C ⁺	2
20000	7.00	11.4	0.42	0.37	0.35		2
20200	3.72	11.2	0.62	0.53	0.51	B	2
		8.4				B ⁺	
						B ⁺	
						B ⁺	
						B ⁺	
						B ⁺	
						B ⁺	

The average ratio values	0.96	1.12	0.87	0.93	0.80	0.83
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* Shifts measured at the halfwidth line position

Indium

In I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2 P^{\circ}_{1/2}$

Ionization energy: 5.7863557 eV = 46 670.106 cm⁻¹

In publication¹ two In I spectral lines are used for the study of Stark broadening parameters in laser induced plasma induced in front of indium target.¹ Before line shape recording the authors¹ took all precautions to ensure correct deconvolution of experimental line profile. Abel procedure is applied and line self-absorption test, carried out. The plasma electron density is measured from the halfwidth of Ar I 4259 Å line while for determination of electron temperature Saha equation is used, see Key data on experiment.

The Stark parameters for the same two spectral lines are measured in Ref. 2 also. The electron temperature, concerning this experiment, reported in the table of Numerical results for In I is derived from graphical presentation of plasma diagnostic data.

For the comparison of experimental Stark halfwidths with SC calculations the data are evaluated within this work (TW) and used for comparison, see table Numerical results for In I.

CR (1990).

References

¹M. Burger, M. Skočić, M. Ljubisavljević, Z. Nikolić, S. Djeniže, Eur. J. D **68**, 223 (2014).

²E. Axente, J. Hermann, G. Socol, L. Mercadier, S. A. Beldjilali, M. Cirisan, C. R. Luculescu, C.

Ristoscu, I. N. Mihailescu, V. Craciun, J. Anal. At. Spectrom. **29**, 553 (2014).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Electron temperature	
1	Nd:YAG laser operating at 532 nm. Laser pulse duration 5ns with repetition rate of 1 Hz providing energy 35 mJ Target: pure indium located in the vacuum chamber filled with argon at the pressure of 6650 Pa Q-switched Nd:YAG laser operating at 266 nm, 4 mJ, repetition rate 10 Hz Target: Indium-zinc oxide The plasma is generated in air ambient	Stark width of the Ar I 4259 Å spectral line	Determined by applying Saha equation to In I 2933 Å and In 2941 Å spectral lines	Plasma observed side-on
2		Stark shift of the Zn I 4722.1 Å	Intensity ratio of the Zn I 3345.0 Å and the Zn I 4722.1 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam

Numerical results for In I

[illegible]

Iron

Fe I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2 \ ^5D_4$

Ionization energy: 7.9024681 eV = 63 737.704 cm⁻¹

Zielinska *et al.*¹ measured the Stark widths and shifts of ten Fe I spectral lines using the gas-metal arc welding (GMAW) processes in an arc discharge between a consumable solid metal electrode and a weld pool. The plasma was generated by a welding set SAFMIG 480 TRS PLUS equipped with a SAFMIG 480 TR 16 kit.

The wire-electrode, liquid metal transferring inside arc and weld pool are protected against air by argon as shielding gas.

The electron density and temperature were determined simultaneously from Stark halfwidths of Ar I 6965.43 Å and Fe I 5383.37 Å lines by using set of empirical formulas¹.

Abel inversion procedure is applied only with lines used for diagnostic purposes.

For control of self-absorption of selected spectral lines, the authors¹ used comparison with fitted Voigt profiles.

The experimental results of Stark parameters are compared with SC theoretical ones calculated in this work (TW) for multiplets 1, 2, 3 and 5. For the multiplets 4, 6 and 7 the set of perturbing energy levels² is not complete ($\Delta S/S \sim -0.95$).

CR (1984, 02, 09).

References

¹S. Zielinska, S. Pellerin, K. Dzierzega, F. Valensi, K. Musiol, F. Briand, J. Phys. D: Appl. Phys.

43, 434005 (2010).

²NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
4466.55	2	4789.65	6	5022.24	7	5576.09	5

4786.81	3	4859.74	1	5569.62	5
4788.76	4	5014.94	7	5572.84	5

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Welding arc set SAFMIG 480 TRS plus SAFMIG 480 TR kit with steel electrodes Pure argon used as shielding gas with a flow of 20 L/min.	Evaluated from Ar I 6965.4 Å and F I 5383.4 Å spectral line Stark widths	Evaluated from Ar I 6965.4 Å and F I 5383.4 Å spectral line Stark widths	Side-on plasma observation Plasma two zones and the Abel inversion is not applied Self-absorption test was not performed

Numerical results for Fe I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	$4p - 5s$	$z \ ^7F^o - e \ ^7D$	4859.74	9325	1.69	0.755	0.72	0.259	0.32	C ⁺ , B	1
2	$4s - 4p$	$b \ ^3P - x \ ^3D^o$	4466.55	9325	1.69	0.273	3.35	0.015	+/-	C ⁺ , C ⁺	1
3	$4s - 4p$	$c \ ^3P - x \ ^3D^o$	4786.81	9325	1.69	0.119	1.56			B	1
4	$4s - 4p$	$b \ ^3H - z \ ^3H^o$	4788.76	9325	1.69	0.134				B	1
5	$4p - 5s$	$z \ ^5F^o - e \ ^5D$	5569.62	9325	1.69	1.090	0.72	0.322	0.29	B, B	1
			5572.84	9325	1.69	1.260	0.84	0.359	0.33	B, B	1
			5576.09	9325	1.69	1.080	0.71	0.304	0.26	B, B	1
6	$4s - 4p$	$a \ ^1D - ^1F^o$	4789.65	9325	1.69	0.177		0.048		B, B	1
7	$4p - 5s$	$z \ ^3F^o - e \ ^3D$	5014.94	9325	1.69	0.799		0.257		B, B	1
			5022.24	9325	1.69	0.791		0.253		B, B	1
The average ratio values							1.32	0.32			

Iron

Fe II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^1 {}^6D_{9/2}$

Ionization energy: $16.19921 \text{ eV} = 130\,655.4 \text{ cm}^{-1}$

Three experimental studies¹⁻³ are devoted to the Stark broadening and shift investigation of Fe II ion lines. These experiments¹⁻³ have in common that the light sources are always laser induced plasma. For two experiments^{1,2} plasma is generated in air at atmospheric pressure. For the first experiment target was iron-copper alloy, while in Ref. 2 the target was borate fusion of Fe_2O_3 oxide in powder form. For the third experiment³ pellet target of hydrate calcium sulfate powder is located in a vacuum chamber filled with argon at $5 \times 10^4 \text{ Pa}$, see report for Ca I.

In two cases^{1,2} plasma is observed side-on, but Abel inversion procedure is not applied, while in the third experiment plasma is observed end-on. The self-absorption test is performed for experiments^{1,2} using curve of growth method. In experiment³, to control self-absorption, emission coefficient was calculated by comparing measured and calculated emission of spectral intensities.

The electron density measurements, for all three experiments, are carried out from the Balmer H_α Stark halfwidth. The electron temperature in experiments^{1,2} is determined from the Boltzmann plot of Fe II spectral lines while in experiment³ Boltzmann plot of Ca I and Ca II lines is used. More details about experimental procedure one can find in Key data on experiments.

For the comparison theory with experiments the results of SC calculations by Dimitrijević⁴ (D) and SC results evaluated in this work (TW) are used. The w_m/w_{TW} ratio for multiplets M5 and M13 is not reported because $\Delta S/S$ is out of limits ($-0.6 < \Delta S/S < 0.1$).

CR (2002).

References

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³M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).

⁴M. S. Dimitrijević, *Astron. Astrophys. Suppl. Ser.* **111**, 565 (1995).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2040.69	13	2406.66	2	2613.82	1	2753.29	26
2051.03	13	2410.52	2	2617.62	1	2755.74	8
2162.02	12	2424.15	17	2621.67	1	2761.81	9
2233.92	14	2463.28	18	2628.29	1	2774.69	21
2279.92	4	2465.91	18	2639.56	22	2779.30	25
2327.40	3	2486.35	18	2664.66	30	2783.69	25
2331.31	5	2514.38	35	2684.75	34	2799.29	24
2343.50	3	2521.09	31	2692.60	34	2831.56	20
2345.34	16	2568.41	15	2703.99	29	2835.71	19
2368.60	6	2585.88	1	2714.41	9	2873.40	33
2375.19	6	2591.54	10	2716.22	29	2875.35	28
2382.04	2	2593.73	10	2730.73	8	2883.71	23
2388.63	2	2598.37	1	2739.55	9	2897.26	27
2395.63	2	2599.40	1	2743.20	8	2926.59	7
2399.24	2	2607.09	1	2746.48	8	2944.40	11
2404.89	2	2611.87	1	2746.98	9	2949.18	32

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm Pulse energy 100 mJ, with 4.5 ns and repetition rate of 20 Hz Target: iron-copper samples. Plasma generated in air at atmospheric pressure	Hydrogen Balmer H_{α} Stark halfwidth	Boltzmann plot of Fe II spectral lines	Plasma observed side-on Abel inversion is not performed
2	Nd:YAG laser at 1064 nm Pulse energy 300 mJ, with 4.5 ns and repetition rate of 20 Hz Target: borate fusion of Fe_2O_3 oxide in powder form. Plasma generated in air at atmospheric pressure	Hydrogen Balmer H_{α} Stark halfwidth	Boltzmann plot of Fe II spectral lines	Plasma observed side-on Abel inversion is not performed
3	Nd:YAG laser at 266 nm Pulse energy 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_{α} Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Fe II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m /w _D	w _m / w _{TW}	d _m (Å)	d _m /d _D	d _m / d _{TW}	Acc.	Ref.
1	4s - 4p	a ⁶ D - z ⁶ D ^o	2585.88	11000	1	0.06	0.64	0.89	0.008	5.96	0.36	C ⁺ ,	3
			2598.37	11000	1	0.06	0.63	0.87	0.008	5.91	0.37	D	3
			2599.40	14800	1	0.045	0.55	0.70				C ⁺ ,	2
				11000	1	0.06	0.63	0.85	0.008	5.91	+/-	D	3
			2607.09	14000	1	0.0394	0.47	0.62				B	1
				11000	1	0.06	0.63	0.87	0.008	5.87	0.37	C ⁺ ,	3
			2611.87	14000	1	0.0368	0.44	0.58				D	1
				11000	1	0.06	0.63	0.86	0.008	5.85	0.37	B	3
			2613.82	14000	1	0.0384	0.46	0.61				C ⁺ ,	1
				11000	1	0.06	0.63	0.86	0.008	5.84	0.37	D	3
			2617.62	14800	1	0.038	0.46	0.61				B	2
			2621.67	14800	1	0.038	0.46	0.61				C ⁺ ,	2
			2628.29	14000	1	0.0396	0.47	0.61				D	1
												B	
												C ⁺ ,	
												D	
2	4s - 4p	a ⁶ D - z ⁶ F ^o	2382.04	11000	1	0.05	0.61	0.82	0.02	+/-	1.03	C ⁺ ,	3
			2388.63	11000	1	0.05	0.61	0.84	0.02		0.91	C ⁺	3
			2395.63	11000	1	0.05	0.61	0.85	0.02		0.88	C ⁺ ,	3
												C ⁺	

			2399.24	11000	1	0.05	0.61	0.83	0.02	0.93	C ⁺ ,	3
			2404.89	14800	1	0.043	0.60	0.77			C ⁺	2
				11000	1	0.05	0.60	0.81	0.02	0.97	C ⁺ ,	3
			2406.66	14800	1	0.038	0.53	0.69			C ⁺	2
			2410.52	11000	1	0.05	0.60	0.81	0.02	0.97	B	3
											C ⁺ ,	
											C ⁺	
											B	
											C ⁺ ,	
											C ⁺	
3	4s -	a ⁶ D - z ⁶ P ^o	2327.40	14800	1	0.036	0.53	0.68			B	2
	4p		2343.50	14800	1	0.036	0.52	0.70			B	2
4	4s -	a ⁶ D - z	2279.92	14800	1	0.032		0.59			B	2
	4p	⁴ F ^o										
5	3d ⁷ -	a ⁴ F - z ⁴ F ^o	2331.31	14800	1	0.056					B	2
	4p											
6	3d ⁷ -	a ⁴ F - z	2368.60	14800	1	0.047		0.68			B	2
	4p	⁴ D ^o	2375.19	14800	1	0.051		0.96			B	2
7	4s -	a ⁴ D - z	2926.59	14000	1	0.0480		0.53			B	1
	4p	⁶ F ^o										
8	4s -	a ⁴ D - z	2730.73	14000	1	0.0500		0.68			B	1
	4p	⁴ F ^o	2743.20	14000	1	0.0515		0.64			B	1
			2746.48	14000	1	0.0540		0.68			B	1
			2755.74	14000	1	0.0540		0.69			B	1
9	4s -	a ⁴ D - z	2714.41	14800	1	0.052		0.57			B	2
	4p	⁴ D ^o	2739.55	14000	1	0.0534		0.69			B	1
				11000	1	0.090		1.00	0.03 +/-		C ⁺ ,	3
			2746.98	14000	1	0.0560		0.59			C ⁺	1
			2761.81	14000	1	0.0530		0.56			B	1
											B	
10	4s -	a ⁴ D - z ⁴ P ^o	2591.54	14800	1	0.047		0.52			B	2

	$4p$		2593.73	14800	1	0.045	0.50	B	2
11	$3d^7 -$ $4p$	$a\ ^4P - z\ ^4P^o$	2944.40	14800	1	0.077	0.66	B	2
12	$3d^7 -$ $4p$	$a\ ^2G - z\ ^2G^o$	2162.02	14800	1	0.043	1.06	B	2
13	$3d^7 -$ $4p$	$a\ ^2G - y\ ^2G^o$	2040.69	14800	1	0.038		B	2
	$4p$		2051.03	14800	1	0.035		B	2
14	$3d^7 -$ $4p$	$a\ ^2H - z\ ^2H^o$	2233.92	14800	1	0.041	0.90	B	2
15	$4s -$ $4p$	$b\ ^4P - y\ ^4P^o$	2568.41	14800	1	0.041	0.49	B	2
16	$4s -$ $4p$	$a\ ^4H - y\ ^4G^o$	2345.34	14800	1	0.038	0.51	B	2
17	$4s -$ $4p$	$b\ ^4F - y\ ^4G^o$	2424.15	14800	1	0.040	0.53	B	2
18	$4s -$ $4p$	$a\ ^4G - x\ ^4F^o$	2463.28	14800	1	0.038	0.66	B	2
			2465.91	14800	1	0.033	0.57	B	2
			2486.35	14800	1	0.035	0.59	B	2
19	$4s -$ $4p$	$b\ ^2P - z\ ^4G^o$	2835.71	14800	1	0.054	0.61	B	2
20	$4s -$ $4p$	$b\ ^2P - z\ ^2D^o$	2831.56	14000	1	0.0490	0.48	B	1
21	$4s -$ $4p$	$b\ ^2P - y\ ^4D^o$	2774.69	14800	1	0.057	0.48	B	2
22	$4s -$ $4p$	$b\ ^2P - z\ ^2P^o$	2639.56	14800	1	0.052	0.56	B	2
23	$4s -$ $4p$	$b\ ^2H - z\ ^4H^o$	2883.71	14800	1	0.055	0.63	B	2
24	$4s -$ $4p$	$b\ ^2H - y\ ^4F^o$	2799.29	14000	1	0.0540	0.49	B	1
25	$4s -$	$b\ ^2H - z$	2779.30	14000	1	0.0532	0.71	B	1

	$4p$	$^2G^o$	2783.69	14000	1	0.0504	0.67	B	1
26	$4s -$	$b \ ^2H - z \ ^2I^o$	2753.29	14000	1	0.0532	0.70	B	1
	$4p$								
27	$4s -$	$a \ ^2F - z$	2897.26	14800	1	0.057	0.44	B	2
	$4p$	$^2D^o$							
28	$4s -$	$a \ ^2F - z$	2875.35	14000	1	0.0489	0.54	B	1
	$4p$	$^2G^o$							
29	$4s -$	$a \ ^2F - z \ ^2F^o$	2703.99	14800	1	0.049	0.52	B	2
	$4p$		2716.22	14800	1	0.045	0.47	B	2
30	$4s -$	$a \ ^2F - y$	2664.66	14000	1	0.0479	0.50	B	1
	$4p$	$^2G^o$							
31	$4s -$	$a \ ^2F - y$	2521.09	14800	1	0.054	0.64	B	2
	$4p$	$^2D^o$							
32	$4s -$	$b \ ^2G - z$	2949.18	14800	1	0.068	0.56	B	2
	$4p$	$^2F^o$							
33	$4s -$	$b \ ^2G - z$	2873.40	14800	1	0.054	0.61	B	2
	$4p$	$^2H^o$							
34	$4s -$	$b \ ^2G - y$	2684.75	14000	1	0.0480	0.67	B	1
	$4p$	$^2H^o$	2692.60	14000	1	0.0501	0.70	B	1
35	$4s -$	$b \ ^2G - x$	2514.38	14800	1	0.048	0.73	B	2
	$4p$	$^2G^o$							
The average ratio values							0.56	0.67	5.89 0.69

In Ref. 1 the authors report that Stark halfwidth data are measured in the temperature interval 12900 – 15200 K.

In this Table the average temperature value of 14000 K is used.

Krypton

Kr II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5 \ ^2P^{\circ}_{3/2}$

Ionization energy: 24.35984 eV = 196 475.4 cm⁻¹

Two pulsed low-pressure gas discharges are set up^{1, 2} for the measurement of Stark broadening parameters of singly charged krypton lines, see Key data on experiments. The Stark broadened line shape study is preceded by careful investigations of the instrumental line shape and self-absorption test. Both investigations are important for correct deconvolution of studied line profiles and proper determination of Stark broadening parameters.

The authors^{1, 2} paid special attention to the test of optical thickness of studied lines. In the table of Numerical results for Kr II experimental and SC calculated data in this work (TW) are reported and compared.

Unfortunately, a number of calculated Stark parameters for multiplets M1, M9-M16, M22, M23, M25-M28, M30-M36, M40, M44, M45, M48 and M49 evaluated in the SC formalism, underestimate the measurements due to the lack of perturbing levels of the upper level of the observed transition. Following difficulty is the selection rules for the transitions with mixed-coupling schemes like LS-JK. Because of above mentioned difficulties the results are not reported. The exemption is M24, where the lack of perturbing levels of the upper level in transition has a minimal impact to the calculated Stark parameters.

In the other cases, in LS-LS coupling scheme, for multiplets M50, M51, M57, M58 and M60, where the $\Delta S/S < -0.6$, calculated Stark parameters also are not reported to prevent inclusion of underestimated results. For the lines from M65 and M66 there are no data in NIST base³. The transitions and multiplet data in these cases are taken from Ref 4, where they are incomplete.

CR (1984, 90, 02, 09).

References

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⁴A. R. Striganov and N. S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms*, Plenum, New York (1968).

Finding list

Wavelength (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.
2086.73	9	2592.48	35	3653.93	42	4691.30	19
2088.15	9	2616.71	33	3663.45	4	4948.50	56
2093.37	10	2620.44	45	3875.44	55	4960.25	54
2096.23	9	2643.06	25	3906.18	64	5033.85	63
2109.79	11	2649.27	25	3912.58	3	5077.23	8
2227.93	14	2695.70	27	3920.08	47	5086.52	63
2250.32	65	2701.34	51	3987.78	3	5143.05	57
2282.68	36	2712.40	32	3994.84	4	5166.80	39
2287.79	66	2716.16	26	3997.96	53	5186.98	38
2301.74	15	2729.46	31	4057.04	20	5200.22	39
2312.02	1	2733.26	49	4065.13	21	5276.50	61
2314.24	23	2742.56	30	4109.25	21	5992.24	2
2315.53	16	2795.81	48	4236.64	41	6022.40	7
2316.32	14	2803.20	40	4386.54	41	6168.80	37
2344.38	15	2833.00	24	4422.72	20	6303.69	7
2353.70	13	2967.25	31	4453.21	58	6605.01	29
2362.75	28	2974.04	31	4475.01	20	6634.37	7
2375.53	12	2978.87	44	4489.88	59	6771.20	18
2426.36	1	2999.84	68	4523.14	41	6870.85	43
2428.33	34	3460.10	5	4556.61	52	7073.98	17
2572.03	22	3470.05	50	4582.98	46	7140.01	6
2589.08	67	3503.25	60	4592.80	62		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Gas discharge in cylindrical Pyrex glass tube Pure krypton continuous flow at a pressure of 3.3×10^3 Pa	Two-laser wavelength (5430 Å and 6328 Å) interferometry	Boltzmann plot of 8 Kr II spectral lines	Plasma observed axially end-on
2	Gas discharge in cylindrical Pyrex glass tube The gas mixture 92% of He and 8% of Kr continuous flow at a pressure of 2.6 kPa	Two-laser wavelength (5430 Å and 6328 Å) interferometry	Boltzmann plot of 12 Kr II spectral lines	Plasma observed axially end-on

Numerical results for Kr II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	$4p^6 - ({}^1D)5p$	${}^2S - {}^2P^o$	2312.02	18000	1	0.271		- 0.065		B ⁺ ,	2
			2426.36	18000	1	5		- 0.072		B ⁺	2
						0.287				B ⁺ ,	
2	$({}^3P)5s - ({}^3P)5p$	${}^4P - {}^4P^o$	5992.24	21000	1	0.542	0.71	- 0.073	0.23	B ⁺ ,	1
										B ⁺	
										B	
3	$({}^3P)5s - ({}^3P)5p$	${}^4P - {}^4D^o$	3912.58	18000	1	0.238	0.86	- 0.041	0.50	B ⁺ ,	2
			3987.78	18000	1	3	0.74	- 0.044	0.52	B ⁺	2
						0.218				B ⁺ ,	
4	$({}^3P)5s - ({}^3P)5p$	${}^4P - {}^2D^o$	3663.45	18000	1	0.186	0.65	- 0.046	0.34	B ⁺ ,	2
			3994.84	18000	1	3	0.66	- 0.043	0.26	B ⁺	2
						0.230				B ⁺ ,	
5	$({}^3P)5s - ({}^3P)5p$	${}^4P - {}^4S^o$	3460.10	18000	1	0.203	0.73	- 0.044	0.33	B ⁺ ,	2
										B ⁺	
6	$({}^3P)4d - ({}^3P)5p$	${}^4D - {}^4P^o$	7140.01	21000	1	0.997	0.87			B ⁺	1
7	$({}^3P)4d - ({}^3P)5p$	${}^4D - {}^4D^o$	6022.40	21000	1	0.800	1.24			B ⁺	1
			6303.69	21000	1	0.971	1.37			B ⁺	1
			6634.37	21000	1	0.878	1.11			B ⁺	1
8	$({}^3P)4d - ({}^3P)5p$	${}^4D - {}^2D^o$	5077.23	21000	1	0.572	0.94	- 0.119	0.48	B ⁺ ,	1
										D	
9	$({}^3P)4d - ({}^3P_2)4f$	${}^4D - {}^2[4]^o$	2086.73	18000	1	0.258				B	2
			2088.15	18000	1	0				B ⁺	2

			2096.23	18000	1	0.251 8 0.228 7					B ⁺	2
10	(³ P)4 <i>d</i> - (³ P ₂)4 <i>f</i>	⁴ D - ² [3] ^o	2093.37	18000	1	0.274 6					B ⁺	2
11	(³ P)4 <i>d</i> - (³ P ₂)4 <i>f</i>	⁴ D - ² [2] ^o	2109.79	18000	1	0.215 3					B ⁺	2
12	(³ P)4 <i>d</i> - (³ P ₂)4 <i>f</i>	⁴ F - ² [4] ^o	2375.53	18000	1	0.236 4					B ⁺	2
13	(³ P)4 <i>d</i> - (³ P ₂)4 <i>f</i>	⁴ F - ² [5] ^o	2353.70	18000	1	0.304 0					B ⁺	2
14	(³ P)4 <i>d</i> - (³ P ₁)4 <i>f</i>	⁴ F - ² [4] ^o	2227.93 2316.32	18000 18000	1 1	0.236 7 0.248 6		0.021			B ⁺ B ⁺ , C ⁺	2 2
15	(³ P)4 <i>d</i> - (³ P ₁)4 <i>f</i>	⁴ F - ² [3] ^o	2301.74 2344.38	18000 18000	1 1	0.294 2 0.325 0		0.017			B ⁺ B ⁺ , C ⁺	2 2
16	(³ P)4 <i>d</i> - (³ P ₀)4 <i>f</i>	⁴ F - ² [3] ^o	2315.53	18000	1	0.262 5					B ⁺	2
17	(¹ D)5 <i>s</i> - (³ P)5 <i>p</i>	² D - ² D ^o	7073.98	21000	1	0.975	0.91				B ⁺	1
18	(¹ D)5 <i>s</i> - (³ P)5 <i>p</i>	² D - ² S ^o	6771.20	21000	1	0.857	0.97				B ⁺	1
19	(¹ D)5 <i>s</i> - (¹ D)5 <i>p</i>	² D - ² F ^o	4691.30	21000	1	0.464	1.48				B ⁺	1
20	(¹ D)5 <i>s</i> - (¹ D)5 <i>p</i>	² D - ² P ^o	4057.04 4422.72 4475.01	21000 21000 21000	1 1 1	0.948 1.095 1.179	1.57 1.83 1.89	- 0.266 - 0.271 - 0.259	1.52 -/+ -/+		B ⁺ , B B ⁺ , B ⁺ , B ⁺	1 1 1
21	(¹ D)5 <i>s</i> - (¹ D)5 <i>p</i>	² D - ² D ^o	4065.13	21000	1	0.815	2.10	- 0.193	1.53		B ⁺	1

			4109.25	21000	1	0.922	2.42	- 0.171	1.59	B ⁺	
										B ⁺ ,	1
										B	
22	$4d - (^3P_2)4f$	$- ^2[2]^o$	2572.03	18000	1	0.327				B ⁺	2
						4					
23	$4d - (^3P_1)4f$	$- ^2[2]^o$	2314.24	18000	1	0.242				B ⁺	2
						0					
24	$(^3P)4d - (^3P_2)4f$	$^4P - ^2[3]^o$	2833.00	18000	1	0.380	1.33	0.030	+/-	B ⁺ ,	2
						0				B ⁺	
25	$(^3P)4d - (^3P_2)4f$	$^4P - ^2[1]^o$	2643.06	18000	1	0.447				B ⁺	2
			2649.27	18000	1	6				B ⁺	2
						0.452					
						2					
26	$(^3P)4d - (^3P_2)4f$	$^2P - ^2[3]^o$	2716.16	18000	1	0.357		$ d < 1$		B ⁺	2
						8					
27	$(^3P)4d - (^3P_2)4f$	$^2P - ^2[2]^o$	2695.70	18000	1	0.374		$ d < 1$		B ⁺	2
						6					
28	$(^3P)4d - (^3P_0)4f$	$^2P - ^2[3]^o$	2362.75	18000	1	0.256				B ⁺	2
						0					
29	$(^3P)4d - (^1D)5p$	$^2F - ^2F^o$	6605.01	21000	1	0.785	1.00			B ⁺	1
30	$(^3P)4d - (^3P_2)4f$	$^2F - ^2[4]^o$	2742.56	18000	1	0.426		0.019		B ⁺ ,	2
						2				B	
31	$(^3P)4d - (^3P_2)4f$	$^2F - ^2[3]^o$	2729.46	18000	1	0.350		0.041		B ⁺ ,	2
			2967.25	18000	1	8		0.028		B	2
			2974.04	18000	1	0.423				B ⁺ ,	2
						1				B	
						0.404				B ⁺	
						9					
32	$(^3P)4d - (^3P_2)4f$	$^2F - ^2[5]^o$	2712.40	18000	1	0.362		0.023		B ⁺ ,	2
						3				B ⁺	
33	$(^3P)4d - (^3P_1)4f$	$^2F - ^2[2]^o$	2616.71	18000	1	0.381				B ⁺	2

34	$(^3\text{P})4d - (^3\text{P}_1)4f$	$^2\text{F} - ^2[4]^\circ$	2428.33	18000	1	² 0.281		0.026		B ⁺ , B ⁺	2
35	$(^3\text{P})4d - (^3\text{P}_1)4f$	$^2\text{F} - ^2[3]^\circ$	2592.48	18000	1	² 0.326		0.029		B ⁺ , B ⁺	2
36	$(^3\text{P})4d - (^3\text{P}_2)5f$	$^2\text{F} - ^2[4]^\circ$	2282.68	18000	1	² 0.281		0.019		B ⁺ , B	2
37	$4d - (^1\text{D})5p$	$- ^2\text{F}^\circ$	6168.80	21000	1	⁵ 0.738	1.41	- 0.057	-/+	B ⁺ , D	1
38	$4d - (^1\text{D})5p$	$- ^2\text{P}^\circ$	5186.98	21000	1	1.507	1.62	- 0.342	1.57	B ⁺ , B ⁺	1
39	$4d - (^1\text{D})5p$	$- ^2\text{D}^\circ$	5166.80	21000	1	0.63	1.17			B ⁺	1
			5200.22	21000	1	1.420	2.54	- 0.259	5.86	B ⁺ , B ⁺	1
40	$4d - (^3\text{P}_2)4f$	$- ^2[1]^\circ$	2803.20	18000	1	0.411		$ d < 2$		B ⁺	2
41	$(^3\text{P})5p - (^3\text{P})6s$	$^4\text{P}^\circ - ^4\text{P}$	4236.64	21000	1	¹ 1.044	1.13	0.390	0.81	B ⁺ , B ⁺	1
			4386.54	21000	1	1.178	1.28	0.440	0.93	B ⁺ , B ⁺	1
			4523.14	21000	1	1.336	1.31	0.529	1.00	B ⁺ , B ⁺ , B ⁺	1
42	$(^3\text{P})5p - (^3\text{P})5d$	$^4\text{P}^\circ - ^4\text{D}$	3653.93	18000	1	0.715	0.72	0.307	0.69	B ⁺ , B ⁺	2
43	$4d - (^1\text{D})5p$	$- ^2\text{F}^\circ$	6870.85	21000	1	⁶ 0.999	1.54			B ⁺	1
44	$4d - (^3\text{P}_2)4f$	$- ^2[3]^\circ$	2978.87	18000	1	0.412				B ⁺	2
45	$4d - (^3\text{P}_1)4f$	$- ^2[2]^\circ$	2620.44	18000	1	⁹ 0.361		0.034		B ⁺ , B ⁺	2
46	$(^3\text{P})5p - (^3\text{P})6s$	$^4\text{D}^\circ - ^4\text{P}$	4582.98	21000	1	⁹ 1.244	1.17	0.506	0.91	B ⁺ , B ⁺	1

47	$(^3\text{P})5p - (^3\text{P})5d$	$^4\text{D}^\circ - ^4\text{D}$	3920.08	18000	1	0.984 3	0.95	0.353	0.72	B ⁺ , B ⁺	2
48	$4d - (^3\text{P}_1)4f$	$- ^2[4]^\circ$	2795.81	18000	1	0.387 5		0.024		B ⁺ , B ⁺	2
49	$4d - (^3\text{P}_0)4f$	$- ^2[3]^\circ$	2733.26	18000	1	0.384 4		0.038		B ⁺ , B ⁺	2
50	$(^3\text{P})5p - (^3\text{P})5d$	$^2\text{P}^\circ - ^2\text{P}$	3470.05	18000	1	0.931 7		0.448		B, B ⁺	2
51	$(^3\text{P})5p - (^1\text{D})5d$	$^2\text{P}^\circ - ^2\text{D}$	2701.34	18000	1	0.355 1		$ d < 1$		B ⁺	2
52	$(^3\text{P})5p - (^3\text{P})5d$	$^2\text{D}^\circ - ^4\text{D}$	4556.61	21000	1	1.327	0.93	0.492	0.75	B ⁺ , B ⁺	1
53	$(^3\text{P})5p - (^3\text{P})5d$	$^2\text{D}^\circ - ^2\text{F}$	3997.96	18000	1	0.897 0	2.40	0.378	3.10	B, B ⁺	2
54	$(^3\text{P})5p - (^3\text{P})6s$	$^4\text{S}^\circ - ^4\text{P}$	4960.25	21000	1	1.303	0.63	0.514	0.49	B ⁺ , B ⁺	1
55	$(^3\text{P})5p - (^3\text{P})5d$	$^4\text{S}^\circ - ^4\text{P}$	3875.44	18000	1	1.422 7	0.97	0.282	+/-	B ⁺ , B ⁺	2
56	$(^3\text{P})5p - (^3\text{P})5d$	$^2\text{S}^\circ - ^4\text{D}$	4948.50	21000	1	2.028	1.18	0.646	0.84	B ⁺ , B ⁺	1
57	$(^3\text{P})5p - (^3\text{P})6s$	$^2\text{S}^\circ - ^2\text{P}$	5143.05	21000	1	1.100		0.300		B ⁺ , B ⁺	1
58	$(^1\text{S})5s - (^1\text{S})5p$	$^2\text{S} - ^2\text{P}^\circ$	4453.21	21000	1	0.680		- 0.146		B ⁺ , C	1
59	$(^1\text{D})5p - (^1\text{D})6s$	$^2\text{F}^\circ - ^2\text{D}$	4489.88	21000	1	1.263	1.43	0.431	+/-	B ⁺ , B ⁺	1
60	$(^1\text{D})5p - (^1\text{D})5d$	$^2\text{F}^\circ - ^2\text{F}$	3503.25	18000	1	1.171 5		0.453		B ⁺ , B ⁺	2
61	$(^1\text{D})4d - (^3\text{P}_2)4f$	$^2\text{D} - ^2[2]^\circ$	5276.50	21000	1	2.095	1.47			B ⁺	1
62	$(^1\text{D})5p - (^1\text{D})6s$	$^2\text{P}^\circ - ^2\text{D}$	4592.80	21000	1	1.585	1.30	0.757	+/-	B ⁺ , B ⁺	1

63	$(^1D)5p - (^1D)6s$	$^2D^o - ^2D$	5033.85	21000	1	2.338	1.50	0.683	1.96	B^+ ,	1
			5086.52	21000	1	1.459	1.00	0.646	1.94	B^+	1
										B^+ ,	
										B^+	
64	$(^1D)5p - (^1D)5d$	$^2D^o - ^2F$	3906.18	21000	1	1.613	1.80			B^+	1
			2250.32	18000	1	0.308				B^+	2
						6					
65	$5s' -$	$^2D - 6^o$	2287.79	18000	1	0.273		0.016		B^+ ,	2
						5				B^+	
			2589.08	18000	1	0.361		0.041		B^+ ,	2
						9				B^+	
66	$4d' -$	$^2D - 11^o$	2999.84	18000	1	0.584				B^+	2
						7					
The average ratio values							1.27		1.16		

Krypton

Kr III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4 \ ^3P_2$

Ionization energy: 35.838 eV = 289 050 cm⁻¹

design of plasma source,¹ line shape testing before final profile recording and plasma diagnostics are identical with Ref .2 of Kr II, compare Key data on experiments for Kr II (Ref.2) and Kr III. After the deconvolution procedure of experimental profiles Stark parameters are obtained and then compared with SC theoretical data evaluated in this work (TW), see table of Numerical results for Kr III. Comments: In multiplet M16 the ratio w_m/w_{TW} differs considerably from all other results. For multiplets M14 and M17 data w_m/w_{TW} are omitted because $\Delta S/S$ are below of -0.6.

For the line 2639.76 Å from M18 there are no data in NIST data base². The transition and multiplet data are taken from Ref 3.

CR (1990, 02).

References

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²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

³A. R. Striganov and N. S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms*, Plenum, New York (1968).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2452.29	17	2628.9	1	2696.59	1	2952.56	6
2457.72	18	2639.76	1	2697.3	1	2992.22	7
2537.57	3	2670.67	13	2806.07	14	2996.60	12
2553.16	3	2679.62	1	2814.48	11	3474.65	10
2554.25	4	2680.32	1	2870.61	15	3507.42	2
2555.13	4	2681.19	1	2892.18	7	3641.34	9

2563.25	16	2690.23	3	2893.68	8
2571.19	5	2694.81	1	2900.04	11

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Gas discharge in cylindrical Pyrex glass tube The gas mixture 92% of He and 8% of Kr with continuous flow at a pressure of 2.6 kPa	Two-laser wavelength (5430 Å and 6328 Å) interferometry	Boltzmann plot of 12 Kr II spectral lines	Plasma observed axially end-on

Numerical results for Kr III

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.									
					density (10^{17} cm^{-3})															
161																				
1	$4d - 5p$	$^5D^o - ^5P$	2628.90	18000	1	0.109	0.92	$ d < 0.02$		B	1									
			2639.76	18000	1	8	1.07	$ d < 0.02$		B	1									
			2679.62	18000	1	0.132	0.91		C	1										
			2680.32	18000	1	2	1.07	$d < 0.02$		B	1									
			2681.19	18000	1	0.111	1.02	$d < 0.02$		B	1									
			2694.81	18000	1	5	0.95	0.0203	0.51	B	1									
			2696.59	18000	1	0.133	0.92	$d < 0.02$		B	1									
			2697.30	18000	1	8	0.96	$d < 0.02$		B, B	1									
						0.127														
						9														
2	$5s - 5p$	$^3S^o - ^3P$	3507.42	18000	1	0.214	0.86	$d < 0$		B ⁺	1									
						6														
			3	$4d - 5p$	$^3F^o - ^3D$	2537.57	18000	1	0.111	0.91		B	1							
						2553.16	18000	1	2	0.93		B	1							
						2690.23	18000	1	0.106	0.82	$d < 0.02$	B	1							
									7											
									0.106											
									9											
						4	$4d - 5p$	$^3F^o - ^3F$	2554.25	18000	1	0.114	0.86	$d < 0.02$	C	1				
									2555.13	18000	1	0	0.91	$d < 0.02$	C	1				
									0.107											
									3											
5	$4d - 5p$	$^3F^o - ^1F$	2571.19	18000	1				0.107	0.84		B	1							
									4											
			6	$4d - 5p$	$^3G^o - ^3D$				2952.56	18000	1	0.137	0.89	$ d < 0.02$	B	1				
												8								
									7	$4d - 5p$	$^3G^o - ^3F$	2892.18	18000	1	0.135	0.87	0.0282	0.58	B,	1
												2992.22	18000	1	4	0.87	$ d < 0.02$	B ⁺	1	
												0.143			B					
												3								
						8	$4d - 5p$	$^3G^o - ^1F$				2893.68	18000	1	0.146	0.89		B	1	
															4					

Lead

Pb I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^4 5d^{10} 6s^2 6p^2$ ($^1/2, ^1/2$)₀

Ionization energy: 7.4166799 eV = 59 819.558 cm⁻¹

Both experiments^{1, 2} are set up to measure Stark broadening parameters of Pb I lines use laser induced plasma as a light source. The side-on plasma observations are employed, and Abel inversion applied in experiment described in Ref. 1. The self-absorption test is carried out before Pb I line profiles are used for Stark parameter measurement. The other experimental details about laser used for plasma generation, target material and plasma diagnostics are described in the table Key data on experiments. The experimental results (with exception of a single halfwidth and shift from Ref. 2) are related to halfwidths reported in Ref. 1. The differences of halfwidths within multiplets frequently exceed 50%, see the table of Numerical results for Pb I. This is in contrast with the study of Ref. 3, where differences within multiplet in most cases do not exceed several percent. Large variations of halfwidths within multiplet are usually an indication of experimental error in halfwidth measurement, see e.g., Ref. 3. This is the cause for an increase of estimated uncertainty of Pb I data from Ref. 1 in the table of Numerical results.

The electron temperature, presented in the Numerical results table for Ref. 2, is derived from graphical presentation of plasma diagnostic data (Fig 7 in Ref 2).

The comparison experiment versus SC calculations is not performed as usual in the similar tables with numerical results. This is because of Pb I highly incomplete set of perturbing levels ($dS/S < -0.6$), which do not fulfill the selection rules for dipole transitions.

CR (1984, 02).

References

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M. Sentis, W. Viöl, Spectrochim. Acta B **101**, 32 (2014).

³W.L. Wiese and N. Konjević, J.Quant.Spectrosc.Radiat.Transfer 28, 185 (1982)

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2170.01	2	2476.39	6	2833.05	1	3739.94	12
2237.43	9	2577.26	6	2873.31	4	4019.63	10
2388.80	9	2613.66	5	3220.53	15	4057.81	3
2393.79	8	2614.18	5	3229.61	14	4062.14	11
2399.60	9	2628.26	7	3240.19	15	4168.03	10
2401.94	6	2663.15	6	3572.73	12	5005.42	12
2411.73	8	2802.00	4	3639.57	3	5201.44	13
2443.83	7	2822.58	5	3671.49	13		
2446.18	7	2823.19	5	3683.46	3		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm, 275 mJ, 7 ns Repetition rate 20Hz Target: Sn-Pb alloy positioned in chamber filled with argon at 6 Torr	Stark width of several Pb I and Pb II spectral lines	Boltzmann plot of seven Pb I and five Pb II spectral lines	Plasma observed side-on
2	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å and 3862.6 Å spectral lines	Plasma observed side-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone

Numerical results for Pb I

No .	Trans. array	Mult.	Wave. (Å)	Temp (K)	Electron density	w_m (Å)	d_m (Å)	Acc.	Ref.	166
					(10^{17} cm $^{-3}$)					
1	$6p^2 - 7s$	(1/2,1/2) - (1/2,1/2) $^\circ$	2833.05	1120 0	1	0.069		B	1	
2	$6p^2 - 6d$	(1/2,1/2) - $^2[3/2]^\circ$	2170.01	1120 0	1	0.102		B	1	
3	$6p^2 - 7s$	(3/2,1/2) - (1/2,1/2) $^\circ$		1120 0	1 1	0.153 0.131		B B	1 1	
			3639.57 3683.46 4057.81	1120 0 1120	1	0.141		B	1	
4	$6p^2 - 6d$	(3/2,1/2) - $^2[5/2]^\circ$		0 1120 0	1 1	0.288 0.137		B B	1 1	
			2802.00 2873.31	1120 0						
5	$6p^2 - 6d$	(3/2,1/2) - $^2[3/2]^\circ$		1120 0	1 1	0.111 0.180		B B	1 1	
			2613.66 2614.18 2822.58 2823.19	1120 0 1120 0	1 1	0.075 0.138		B B	1 1	
6	$6p^2 - 7s$	(3/2,1/2) - (3/2,1/2) $^\circ$		1120 0	1 1	0.109 0.092		B B	1 1	
			2401.94 2476.39 2577.26 2663.15	1120 0 1120 0	1 1	0.090 0.098		B B	1 1	
7	$6p^2 - 8s$	(3/2,1/2) - (1/2,1/2) $^\circ$	2443.83 2446.18 2628.26	1120 0 1120	1 1 1	0.118 0.123 0.099		B B B	1 1 1	
8	$6p^2 - 7d$	(3/2,1/2) - $^2[5/2]^\circ$		0 1120 0						
			2222.52	1120	1	0.202		B	1	

Lead

Pb III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^{10} 6s^2$ 1S_0

Ionization energy: 31.9373 eV = 257 592 cm⁻¹

The measurement of Stark broadening parameters of Pb III lines are carried out by the same author¹ and equipment used for Pb I lines, see report for Pb I. The only difference from Pb I experiment is plasma diagnostics based now on the shapes and intensities of Pb III lines. The Abel inversion is performed, and self-absorption check carried out. More details about plasma source one can find in the table Key data on experiment. The experimental results for the Stark broadening Pb III halfwidths are reported in the table Numerical results for Pb III.

Transitions and multiplets are given in accordance with NIST Database² notation. The results in the table are compared with corresponding SC theoretical data calculated in this work (TW). The comparison of experimental halfwidths within multiplets M10, M11, M13 and M14 shows large differences of halfwidths, which is usually an indication of an experimental error in halfwidth measurement, see report for Pb I lines.

The comments of importance for SC calculations: a) the energy levels are not of single kind i.e. they are mixed, which makes calculations difficult and not very accurate, b) in the case of the multiplets M7, M8, M12, M14 and M15 incomplete set of perturbing levels is available only, $\Delta S/S < -0.6$, and the ratio w_m/w_{TW} is omitted in the Numerical results table. From these reasons the average value of the w_m/w_{TW} ratio is not given in the table.

CR (2009).

References

¹A. Alonso-Medina, Spectrochim. Acta B **66**, 439 (2011).

²NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
3043.85	13	3706.02	2	4499.34	3	5380.97	10

3137.81	13	3728.69	2	4571.21	1	5523.97	10
3176.50	13	3735.95	15	4761.12	6	5779.41	8
3530.17	4	3854.08	5	4798.59	6	5857.96	10
3589.87	14	3951.92	11	4826.86	1		
3655.80	14	4141.60	11	4855.06	9		
3689.31	5	4272.66	7	5207.70	12		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm, 290 mJ, 7 ns Repetition rate 20 Hz Target: Lead sample purity 99.99% positioned in vacuum chamber filled with argon at 6 Torr	Stark width of Pb III 3854.1 Å and 4761.1 Å spectral lines	Pb III spectral lines	Plasma observed side-on

Numerical results for Pb III

No.	Trans. array	Mult.	Wave. (Å)	Temp (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_{TW}	Acc.	Ref.	170
1	7 <i>p</i> – 8 <i>s</i>	(1/2, 3/2) ^o – ³ S		2140	1	1.96	1.64	B	1	
			4571.21	0	1	1.61	1.23	B	1	
			4826.86	2140						
2	7 <i>p</i> – 8 <i>s</i>	(1/2, 1/2) ^o – ³ S		2140	1	0.91	1.18	B	1	
			3706.02	0	1	0.94	1.20	B	1	
			3728.69	2140						
3	7 <i>p</i> – 8 <i>s</i>	(1/2, 3/2) ^o – ¹ S		2140	1	0.98	0.83	B	1	
			4499.34	0						
4	7 <i>p</i> – 8 <i>s</i>	(1/2, 1/2) ^o – ¹ S		2140	1	0.60	0.82	B	1	
			3530.17	0						
5	7 <i>s</i> – 7 <i>p</i>	³ S – (1/2, 3/2) ^o	3689.31	2140	1	0.69	2.20	B	1	
			3854.08	0	1	0.82	1.96	B	1	
				2140						
6	7 <i>s</i> – 7 <i>p</i>	³ S – (1/2, 1/2) ^o	4761.12	2140	1	1.01	1.89	B	1	
			4798.59	0	1	1.09	2.16	B	1	
				2140						
7	7 <i>s</i> – 7 <i>p</i>	¹ S – (1/2, 3/2) ^o	4272.66	2140	1	0.42		B	1	
				0						
8	7 <i>s</i> – 7 <i>p</i>	¹ S – (1/2, 1/2) ^o	5779.41	2140	1	1.79		B	1	
				0						
9	6 <i>p</i> ² – 7 <i>p</i>	³ P – (1/2, 3/2) ^o	4855.06	2140	1	1.45	2.30	B	1	
				0						
10	6 <i>d</i> – 7 <i>p</i>	³ D – (1/2, 3/2) ^o	5380.97	2140	1	2.00	2.70	B	1	
			5523.97	0	1	2.12	2.63	B	1	
			5857.96	2140	1	1.28	1.26	B	1	
				0						
11	6 <i>d</i> – 7 <i>p</i>	¹ D – (1/2, 3/2) ^o		2140	1	0.57	2.14	B	1	
			3951.92	0	1	2.23	4.75	B	1	
			4141.60	2140						
				0						
12	6 <i>d</i> – 7 <i>p</i>	¹ D – (1/2, 1/2) ^o		2140	1	1.89		B	1	
			5207.70	0						

Lead

Pb IV

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^{10} 6s^2 S_{1/2}$

Ionization energy: 42.33256 eV = 341 435.1 cm⁻¹

Only Ref. 1 reports Stark halfwidth data of Pb IV spectral lines. The Pb IV lines are observed, together with Pb V spectra, in the pulsed helium discharge. The spectral lines are generated in discharge with cylindrical lead plates located in the homogenous part of the discharge.

Comments about the organization of Numerical results table:

- In the table, for the multiplets and transitions notification we used data from NIST Database² while in Ref. 1 the authors applied data from Ref. 3.

- It should be noted here that in Ref. 2 there is only an incomplete list of spectral line wavelengths without transition data.

- All transition and multiplet data and the missing wavelengths are derived from the table of energy levels in Ref. 2.

- In Ref. 1 the lines are ordered by increasing wavelengths. In this paper, the lines are ordered according to the increasing quantum number l of the lower transition level. In addition, the lines are also grouped by multiplets, as in the case of M6, M10, M16, M18 and M19.

The comparison between SC theoretical and experimental Stark line halfwidths, using data from Ref. 4 (H) and data calculated in this work (TW), are reported only if input data for theoretical calculations are available. These two sets of theoretical data show good mutual agreement with the average ratio values of 1.11 and 1.08.

References

¹S. Bukvić, S. Djeniže, Z. Nikolić, A. Srećković, *Astron. Astrophys.* **529**, A83 (2011).

²NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

³M. F. Craford, A. B. McLay, A. M. Crooker, *Proceed. Roy. Soc. London Ser. A* 455 (1937).

⁴R. Hamdi, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Brechot, *Month. Not. Roy.*

Astron. Soc. **431**, 1039 (2013).

Finding list

Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.
2042.58	5	2461.49	17	3002.71	16	3567.15	13
2049.34	1	2497.18	7	3052.56	19	3962.48	16
2151.96	15	2637.73	8	3062.37	10	4049.80	19
2154.01	3	2640.45	4	3071.24	17	4496.15	12
2177.46	18	2733.06	9	3145.44	20	4534.60	2
2359.53	6	2864.24	10	3221.17	16	4605.40	11
2417.61	6	2978.14	17	3560.76	14		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure arc The lead atoms are sputtered from thin cylindrical lead plate located inside axial part of the discharge tube at it ends Carrier gas was 90% He + 7% N ₂ + 3% O ₂ at the pressure of 665 Pa	Stark width of 3086 Å Si III and the He II P _α 4686 Å spectral lines	Intensity ratio between Si III (3086.2 Å and 3093.4 Å) and Si IV 3149.6 Å spectral lines	Plasma observed end-on

Numerical results for Pb IV

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_H	w_m/w_{TW}	Acc .	Ref .
1	$5f - 5g$	$^2F^o - ^2G$	2049.34	20000	1	0.493	2.60	1.99	B ⁺	1
2	$5g - 6h$	$^2G - ^2H^o$	4534.60	23300	1	3.010	1.16	0.92	B ⁺	1
3	$6p - 6s^2$	$^2P^o - ^2D$	2154.01	22000	1	0.050	1.23	1.25	B	1
4	$6p - 5g$	$22^o - ^2G$	2640.45*	20000	1	0.422			B ⁺	1
5	$6p - 7d$	$13^o - ^2D$	2042.58	20000	1	0.249			B	1
6	$6p - 7d$	$15^o - ^2D$	2359.53	21700	1	0.181			B ⁺	1
			2417.61	22600	1	0.215			B ⁺	1
7	$6p - 7d$	$16^o - ^2D$	2497.18*	22300	1	0.109			B ⁺	1
8	$6p - 7d$	$17^o - ^2D$	2637.73*	23000	1	0.242			B ⁺	1
9	$6p - 7d$	$18^o - ^2D$	2733.06*	20000	1	0.672			B ⁺	1
10	$6d - 5f$	$^2D - ^2F^o$	2864.24	23800	1	0.494	1.22		B ⁺	1
			3062.37*	22200	1	0.225	1.04		B ⁺	1
11	$6d - 6p$	$^2D - 14^o$	4605.40	23300	1	0.532			B ⁺	1
12	$6d - 6p$	$^2D - 15^o$	4496.15	23300	1	0.435			B ⁺	1
13	$6d - 6p$	$^2D - 18^o$	3567.15*	21800	1	0.245			B ⁺	1
14	$6d - 6p$	$^2D - 19^o$	3560.76*	21800	1	0.252			B ⁺	1
15	$6d - 6p$	$^2D - 21^o$	2151.96	23000	1	0.100			B	1
16	$6d - 7p$	$^2D - ^2P^o$	3002.71*	23000	1	0.185	0.70		B	1
			3221.17	23000	1	0.312	1.00	0.98	B ⁺	1
			3962.48	22600	1	0.470	0.98	1.00	B ⁺	1
17	$7s - 6p$	$^2S - 21^o$	2177.46	23000	1	0.053			C ⁺	1
18	$7s - 7p$	$^2S - ^2P^o$	3052.56	22200	1	0.255	0.87	0.87	B ⁺	1
			4049.80	23800	1	0.615	1.20	1.24	B ⁺	1
19	$7p - 7d$	$^2P^o - ^2D$	2461.49*	23200	1	0.249	0.80	0.92	B ⁺	1
			2978.14	23000	1	0.369	0.92	0.90	B ⁺	1
			3071.24*	22600	1	0.433	0.93			
20	$7p - 8s$	$^2P^o - ^2S$	3145.44*	21000	1	0.392	0.92	0.70	B ⁺	1
The average ratio values							1.11	1.08		

*The wavelengths and the transition data are derived from the table of energy levels in Ref. 2.

Lead

Pb V

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^{10} \ ^1S_0$

Ionization energy: [68.8] eV = [555 000] cm⁻¹

The authors¹ of an experiment set up for measurement Stark broadening halfwidths of

Pb V lines used, as a light source, discharge tube 14 cm long and 5 mm internal diameter. Lead and silicon (used for electron temperature measurements) species are introduced in discharge by sputtering of lead and glass tube wall. All other details about plasma source, electron density and temperature diagnostics one can find in the table Key data on experiment. It is important to mention that self-absorption test is carried out before halfwidth measurement and Stark broadening parameter determination. The values of measured Stark halfwidths one can find in the table of Numerical results for Pb V. Unfortunately, in NIST data tables² there is no required energy level data for SC calculations of measured Pb V lines.

References

¹S. Bukvić, S. Djeniže, Z. Nikolić, A. Srećković, *Astron. Astrophys.* **529**, A83 (2011).

²NIST Atomic Spectra Database: <https://www.nist.gov/pml/atomic-spectra-database>

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc The lead atoms are sputtered from thin cylindrical lead plate located inside discharge tube Carrier gas was 90% He + 7% N ₂ + 3% O ₂ at the pressure of 665Pa	Stark width of 3086 Si III and the He II P _α 4686 spectral lines	Intensity ratio between Si III (3086.2 Å and 3093.4 Å) and Si IV 3149.6 Å spectral lines	Plasma observed axially end-on

Numerical results for Pb V

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	Acc	Ref
1			2142.55	20300	1	0.067	B	1
2			2167.97	21500	1	0.079	B	1
3			2276.66	23000	1	0.083	B	1
4			2424.81	22600	1	0.038	B	1

Lithium

Li I

Ground state: $1s^2 2s \ ^2S_{1/2}$

Ionization energy: $5.391714996 \text{ eV} = 43487.11420 \text{ cm}^{-1}$

Two laser-induced plasma experiments^{1,2} are used for the study Li I 4602.8 Å and 4971.7 Å lines. The 4602.8 Å line with forbidden component is used in Ref. 1 for plasma electron density diagnostic purposes, while 4971.7 Å line, in conjunction with Stark broadening parameters^{3,4}, is used for verification electron density measurements obtained using 4602.8 Å. Because both lines are used as plasma diagnostic tool, the Ref. 1 is eliminated from further study of Stark broadening in this review.

Since Thomson scattering is used for independent electron density and electron temperature plasma diagnostics in Ref. 2, the line shape recording of the 4971.7 Å line may be used for the study of Stark broadening parameters including comparison of experimental data with corresponding SC results from Ref. 3, 4 and this work, see Numerical results for Li I. In theoretical calculations from Ref. 3 (G) and in this work (TW) both electron and Li^+ ions impacts are taken into account, while for calculations from Ref. 4 (DSB) electron impacts are taken into account only.

Comment: In both papers^{1,2} the 4971.7 Å line is mentioned as single line. From the NIST data base⁵ one can see that in multiplet $2p \ ^2P^\circ - 4s \ ^2S$ exist two very close lines 4971.66 Å and 4971.75 Å from the same multiplet with S values 0.42 and 0.84 respectively.

CR (1976, 84).

References

¹M. Cvejić, E. Stambulchik, M. R. Gavrilović, S. Jovićević, N. Konjević, *Spectrochim. Acta B*

100, 86 (2014).

²K. Dzierzega, T. Pieta, W. Zawadzki, E. Stambulchik, M. Gavrilović-Božović, S. Jovićević, B. Pokryzwka, *Plasma Sources Sci. Technol.* **27**, 025013 (2018).

³H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).

⁴M. S. Dimitrijević, S. Sahal-Brechot, J. Quant. Spectrosc. Radiat. Transfer **46**, 41 (1991).

⁵NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser 1064 nm, 15 ns, 50 mJ Target: alumina pallet Al ₂ O ₃ : Li ₂ CO ₃ : MgCO ₃ (9:4:1) Plasma was formed in air at atmospheric pressure	Halfwidth of Li I 4971.7 Å spectral line	Boltzmann plot of five Li I spectral lines	Plasma observed side-on
2	Nd:YAG laser 1064 nm, 4.5 ns, 3.5 mJ Repetition rate 10 Hz Target: alumina pallet Al ₂ O ₃ : Li ₂ CO ₃ : MgCO ₃ (9:4:1) The chamber was filled by argon flow at 200 mbar	Thomson scattering Nd:YAG laser 532 nm, 6.0 ns, 10 mJ	Thomson scattering Nd:YAG laser 532 nm, 6.0 ns, 10 mJ	Plasma observed side-on

Numerical results for Li I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	Acc.	Ref
1	2p - 4s	² P° - ² S	4971.75	12100	0.355	1.88	0.85	1.15	0.73	B ⁺	2
				13900	0.452	2.38	0.81	1.13	0.69	B ⁺	2
				14900	0.618	3.21	0.79	1.11	0.67	B ⁺	2
				16000	0.694	3.91	0.84	1.19	0.71	B ⁺	2
				18900	1.091	6.26	0.82	1.21	0.69	B ⁺	2
				22800	1.422	8.53	0.82	1.25	0.70	B ⁺	2
The average ratio values							0.61	1.17	0.70		

Magnesium

Mg I

Ground state: $1s^2 2s^2 2p^6 3s^2 \ ^1S_0$

Ionization energy: $7.646236 \text{ eV} = 61\,671.05 \text{ cm}^{-1}$

Two experiments with laser induced plasma as a light source are used for the study of Stark broadening of Mg I lines. The experiment described in Ref. 1 is carried out at atmospheric pressure with the pellet target made of three mixed compressed powders, see Ref. 1 Key data on experiments, where one can also find details of the second study.² The second experiment is described in several reports, starting with Ca I, Ca II and C I. In both experiments self-absorption test is carried out before recorded Mg I line is used for Stark parameters determination. The Abel inversion is applied in Ref. 1 where side-on plasma observations are performed. According to the authors in Ref. 2 the end-on plasma observations under angle of 15° from the laser beam does not require Abel inversion. The electron temperatures in Ref. 2, reported in the table of Numerical results, are derived from graphical presentation of plasma diagnostic data.

The experimental Mg I Stark broadening parameters are compared with results of SC calculations whenever available^{3,4} (G, DSB) including this work (TW).

Comments:

In Ref. 1 the average value of the wavelength for the multiplet is given only. For example:

M3: 3835.3* (Ref. 1)

M3 NIST⁵: 3829.3549, 3832.2996, 3832.3037, 3838.2918, 3838.2943

Å

M5 only single line exists 5528.4047 Å (5528.4*)

M6 only single line exists 4702.9909 Å (4702.9*)

CR (1976, 84, 09).

References

¹M. Cvejić, M. R. Gavrilović, S. Jovičević, N. Konjević, *Spectrochim. Acta B* **85**, 20 (2013).

²M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).

³H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).

⁴M. S. Dimitrijević, S. Sahal-Brechot, *Bull. Astron. Belgrade* **149**, 31 (1994).

Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.	Wavelength h (Å)	No.
2776.69	4	2852.13	1	3838.29	3	5183.60	2
2778.27	4	3829.36	3	4702.99	6	5528.41	5
2781.42	4	3832.29	3	5167.32	2		
2782.97	4	3835.30	3	5172.68	2		

⁵NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser 1064 nm, 15 ns, 50 mJ Target: Powder mixture Al_2O_3 , Li_2CO_3 , MgCO_3 compressed in cylindrical pellet 8 mm diameter, 2 mm thick Plasma formed in air at atmospheric pressure	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Mg I and Al II spectral lines	Plasma observed side-on
2	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in vacuum chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Mg I

No.	Trans. array	Mult.	Wave. (\AA)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (\AA)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	d_m (\AA)	d_m/d_G	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	$3s^2 - 3p$	$^1\text{S} - ^1\text{P}^o$	2852.13	11000	1	0.17	1.96	2.34	1.90	0.085	1.81	1.56	1.42	C^+ , C^+	2

2	$3p-4s$	$^3P^o -$	5167.32	11000	1	0.90	1.27	1.68	1.22	0.5	1.13	1.16	1.02	B, B	2
		3S	5172.68	11000	1	0.90	1.27	1.68	1.22	0.5	1.13	1.15	0.94	B, B	2
			5183.60	11000	1	0.90	1.26	1.67	1.21	0.5	1.12	1.15	0.94	B, B	2
3	$3p-3d$	$^3P^o -$	3835.30	6464	0.67	1.2	0.74	1.15	0.71					B ⁺	1
		3D	*	6412	0.72	1.2	0.68	1.07	0.66					B ⁺	1
				6287	0.82	1.3	0.65	1.02	0.62					B ⁺	1
				6326	0.91	1.4	0.63	0.99	0.61					B ⁺	1
				6355	0.99	1.5	0.62	0.98	0.60					B ⁺	1
				6340	1.04	1.6	0.63	0.99	0.60					B ⁺	1
				6389	1.08	1.6	0.61	0.95	0.58					B ⁺	1
				6434	1.09	1.7	0.64	1.00	0.61					B ⁺	1
				11000	1	2.70	1.13	1.64	1.07	- 0.45	0.90	3.43	0.81	B, C ⁺	2
			3829.36	11000	1	2.70	1.13	1.64	1.06	- 0.45	0.90	3.42	0.80	B, C ⁺	2
			3832.29	11000	1	2.70	1.13	1.64	1.07	- 0.45	0.90	3.42	0.84	B, C ⁺	2
			3838.29												
4	$3p-3p^2$	$^3P^o -$	2776.69	11000	1	0.07			0.88	0.01			0.17	C, D	2
		3P	2778.27	11000	1	0.07			9.88	0.01			+/-	C, D	2
			2781.42	11000	1	0.07			0.79	0.01			0.14	C, D	2
			2782.97	11000	1	0.07			0.67	0.01			0.11	C, D	2
5	$3p-4d$	$^1P^o -$	5528.41	6464	0.67	3.7	1.17	1.55	1.08					B ⁺	1
		1D	*	6412	0.72	3.7	1.09	1.44	1.01					B ⁺	1
				6287	0.82	4.2	1.09	1.44	1.01					B ⁺	1
				6326	0.91	4.6	1.07	1.42	0.99					B ⁺	1
				6355	0.99	4.9	1.05	1.39	0.97					B ⁺	1
				6340	1.04	5.1	1.04	1.38	0.96					B ⁺	1
				6389	1.08	5.3	1.04	1.38	0.96					B ⁺	1
				6434	1.09	5.3	1.03	1.36	0.95					B ⁺	1
6	$3p-5d$	$^1P^o -$	4702.99	6464	0.67	7.1	1.03	1.45	0.93					B ⁺	1
		1D	*	6412	0.72	7.4	1.00	1.41	0.90					B ⁺	1
				6287	0.82	7.8	0.93	1.31	0.84					B ⁺	1
				6326	0.91	8.6	0.92	1.30	0.83					B ⁺	1

6355	0.99	9.0	0.88	1.25	0.80				B ⁺	1
6340	1.04	9.1	0.85	1.20	0.77				B ⁺	1
6389	1.08	9.3	0.84	1.18	0.76				B ⁺	1
6434	1.09	9.3	0.83	1.17	0.75				B ⁺	1
The average ratio values			0.98	1.36	0.90	1.13	2.18	0.72		

Magnesium

Mg II

Ground state: $1s^2 2s^2 2p^6 3s^2 S_{1/2}$

Ionization energy: $15.035271 \text{ eV} = 121\,267.64 \text{ cm}^{-1}$

From the very beginning of reviewing Stark broadening publications in the year 1976 several Mg II studies appeared until year 2005 but always with gas discharge as a plasma source. Recently, two laser plasma induced experiments^{1,2} are used for the study of Stark broadening parameters of Mg I and Mg II. Since same equipment and experimental procedures are used here for the study of Mg II lines (see, report for Mg I and compare Key data on experiments for Mg I and Mg II), the details and experimental procedures one can find already described in Mg I report. These two sets of experimental^{1,2} results are compared with two sets of SC calculated data evaluated using Ref. 3 (G) (Appendix V) and from Ref. 4 (DSB). The SC results from this work (TW) are also included. Thus, all data and comparisons for Mg II one can find in the table Numerical results for Mg II.

CR (1976, 84, 09).

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Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2790.78	2	2928.63	1	4481.13	3		
2798.00	2	2936.51	1				

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser 1064 nm, 15 ns, 50 mJ Target: Powder mixture Al_2O_3 , Li_2CO_3 , MgCO_3 compressed in cylindrical pellet 8 mm diameter, 2 mm thick Plasma formed in air at atmospheric pressure	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Mg I and Al II spectral lines	Plasma observed side-on
2	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Mg II

No.	Trans. array	Multipl et	Wavelengt h (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	$3p - 4s$	$^2P^o - ^2S$	2928.63	11000	1	0.5	1.62	1.78	1.65	0.23	1.43	1.82	1.42	B, B	2
			2936.51	11000	1	0.5	1.61	1.77	1.64	0.23	1.42	1.81	1.41	B, B	2
2	$3p - 3d$	$^2P^o - ^2D$	2790.78	11000	1	0.3	1.69	1.58	1.72	0.09	1.10	2.98	1.13	B, B	2
			2798.00	11000	1	0.3	1.68	1.57	1.71	0.09	1.10	2.97	1.11	B, B	2
3	$3d - 4f$	$^2D - ^2F^o$	4481.13	6464	0.67	1.9	0.89	1.13	0.95					B ⁺	1
				6412	0.72	1.9	0.83	1.05	0.88					B ⁺	1
				6287	0.82	2.1	0.8	1.01	0.85					B ⁺	1
				6326	0.91	2.2	0.75	0.96	0.80					B ⁺	1
				6355	0.99	2.3	0.73	0.93	0.77					B ⁺	1
				6340	1.04	2.4	0.72	0.91	0.77					B ⁺	1
				6389	1.08	2.5	0.72	0.92	0.77					B ⁺	1
				6434	1.09	2.5	0.72	0.91	0.77					B ⁺	1
The average values							1.06	1.21	1.11		1.26	2.35	1.27		

Manganese

Mn I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2 \ ^6S_{5/2}$

Ionization energy: $7.4340380 \text{ eV} = 59\,959.560 \text{ cm}^{-1}$

Three experiments¹⁻³ are devoted to the study of Stark broadening parameters of Mn I lines. In Ref. 1 measurements of the Stark broadening of five Mn I lines in typical laser-induced plasma experiment. The authors applied single and double pulse configuration with a series of Fe-Mn alloy samples having Mn concentration ranging from 6% to 30%. The effects of self-absorption on the measured line shapes are studied in detail. The experimental results show that self-absorption is much higher with double pulse laser-induced plasmas in comparison with single pulse. After measurement of the electron density, the Stark broadening parameters of five neutral Mn I lines are determined, and the results compared with the theoretical and available experimental data. More details about experiment and results for measured Mn I lines one can find in two standard tables: Key data on experiments and Numerical results for Mn I lines where they are compared with SC theoretical data evaluated in this work. Here only one comment that electron temperature presented in the table of Numerical results is taken from Fig. 4 in Ref. 1.

Zielinska et al.² measured the Stark widths and shifts of fifteen Mn I spectral lines using the gas-metal arc welding (GMAW) processes in an arc discharge between a consumable solid metal electrode and a weld pool. The plasma was generated by a welding set SAFMIG 480 TRS PLUS equipped with a SAFMIG 480 TR 16 kit. The wire-electrode, liquid metal transferring inside arc and weld pool are protected against air by argon as shielding gas.

The electron density and temperature were determined simultaneously from Stark halfwidths of Ar I 6965.43 and Fe I 5383.37 lines by using set of empirical formulas.² Abel inversion procedure is applied only with lines used for diagnostic purposes. For control of self-absorption of selected spectral lines, the authors² used comparison with fitted Voigt profiles.

The authors of Ref. 3 report the experimental Stark widths of Mn I lines belonging to multiplets $z \ ^6P^\circ \rightarrow a \ ^6S$ and $z \ ^6D^\circ \rightarrow a \ ^6D$ in long spark induced by laser. The used target is aluminum alloy containing 80 ppm of manganese to avoid strong self-absorption of Mn I lines. The electron

density of plasma is estimated by Mg I (5172.68 Å) and Al II (2816.18 Å) lines, is within the range of $(4-30) \times 10^{16} \text{ cm}^{-3}$. The spatial profiles of plasma temperature and electron density along the axis of long spark show that both values are lower than for spherical plasma. No Stark shifting is observed for the lines in studied multiplets.

Comments about the comparison between reported experimental results for Mn I Stark broadening parameters and corresponding SC data calculated in this work (TW): For the multiplets 1, 2, 4, 6 and 7 the sets of perturbing energy levels are not complete ($\Delta S/S \sim -0.95$) and the comparison is missing. The comparison for multiplets 3 and 5 is correctly performed.

The average value for w_m/w_{TW} is given only.

CR(2009).

References

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Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2794.82	2	4058.93	4	4502.22	7	4783.42	5
4030.76	1	4464.68	7	4754.04	5	4823.52	5
4033.07	1	4470.14	7	4761.53	6	5420.36	3
4034.49	1	4472.79	7	4762.38	6	5516.77	3
4041.36	4	4490.08	7	4765.86	6		
4048.76	4	4498.90	7	4766.43	6		

Key data on experiments

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser with two collinear pulses with interpulse delay of 2 μ s at 1064 nm, 12 ns, 60 mJ Target: Fe-Mn alloy in Ar at atmospheric pressure	H $_{\alpha}$ Stark halfwidth	Boltzmann plot of six Fe I and four Fe II spectral lines	Plasma observed side-on Abel inversion not performed
2	Welding arc set SAFMIG 480 TRS plus SAFMIG 480 TR kit with steel electrodes. Pure argon used as shielding gas with a flow of 20 L/min	Evaluated from Ar I 6965.4 Å and F I 5383.4 Å spectral line Stark widths	Evaluated from Ar I 6965.4 Å and F I 5383.4 Å spectral line Stark widths	Plasma observed side-on Plasma is with two zones and the Abel inversion was not applied Self-absorption test is not performed
3	Nd:YAG laser at 532 nm, 8 ns, 83 mJ Target: Al alloy with Cu(4.10%), Li(1.10%), Mg(0.89%), Ag(0.40%) and 80 ppm manganese Plasma induced in air at atmospheric pressure	Stark halfwidth of Mg I 5172 Å and Al II 2816 Å spectral lines	The intensity ratio of Mn I 4034 Å and Mn I 4041 Å spectral lines	Plasma observed side-on Abel inversion not performed

Numerical results for Mn I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Re f.
1	$4s^2 - 4p(^3P^o)$	a $^6S - z$ $^6P^o$	4030.76	13800	0.1	0.005				C ⁺	1
				10000	1	0.075				B	3
			4033.07	13800	0.1	0.006				B	1
				10000	1	0.070				B	3
			4034.49	10000	1	0.055				C ⁺	3
2	$4s^2 - 4p(^3P^o)$	a $^6S - y$ $^6P^o$	2794.82	13800	0.1	0.008				B	1
3	$4s - 4p(^1P^o)$	a $^6D - y$ $^6P^o$	5420.36	9325	1.69	0.357	1.83	0.056	+/-	C ⁺ ,	2
			5516.77	9325	1.69	0.279	1.39			C ⁺	2
										B	
4	$4s - 4p$	a $^6D - z$ $^6D^o$	4041.36	13800	0.1	0.006				B	1
				10000	1	0.095				B	3
			4048.76	10000	1	0.100				C ⁺	3
			4058.93	10000	1	0.125				B	3
5	$4p(^3P^o) - 5s$	z $^8P^o - e$ 8S	4754.04	9325	1.69	1.11	1.10	0.408	0.61	B, C ⁺	2
			4783.42	9325	1.69	1.15	1.13	0.438	0.65	B, C ⁺	2
			4823.52	9325	1.69	1.26	1.21	0.442	0.65	B, C ⁺	2
6	$4s - 4p$	a $^4D - z$ $^4F^o$	4761.53	13800	0.1	0.018				B	1
				9325	1.69	0.259		0.048		B, C ⁺	2
			4762.38	9325	1.69	0.425		0.058		B, C ⁺	2

7	4s - 4p	a ⁴ D - z ⁴ D°	4765.86	9325	1.69	0.280	0.050	B, C ⁺	2
			4766.43	9325	1.69	0.351	0.056	B, C ⁺	2
			4464.68	9325	1.69	0.322	0.075	B, C ⁺	2
			4470.14	9325	1.69	0.291		B	2
			4472.79	9325	1.69	0.278		B	2
			4490.08	9325	1.69	0.274		B	2
			4498.90	9325	1.69	0.286		B	2
			4502.22	9325	1.69	0.312		B	2

The average ratio values

1.33

Manganese

Mn II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1 {}^7S_3$

Ionization energy: $15.63999 \text{ eV} = 126\,145.0 \text{ cm}^{-1}$

The description of equipment, experimental procedure and used plasma diagnostic techniques for the measurement of Stark broadening parameters of seven Mn II lines one can find in a preceding report for Mn I lines. Namely, both studies are described in the same reference (Ref. 1 for Mn I and Mn II). Ref. 1 presents data for nine Mn II lines, but two lines are not identified and only results for seven lines are analyzed in this report. The experimental results and comparisons with SC calculations are in separate reports for Mn I and in the present report for Mn II, see the table of Numerical results for Mn II.

In Ref. 2 Stark widths of 41 and shifts of 30 Mn II lines, in the wavelengths range 2300–3500 Å, are measured using laser-induced plasma source. The target is made of fused glass samples with varying manganese concentration to allow search for minimum of the error due to self-absorption during Stark width measurements. This procedure enables study of narrow Mn II resonance lines.

The results for Mn II Stark parameters are compared with experimental and theoretical values available in the literature at the time of Ref. 2 is published.

Here we shall mention only that two sets of SC data (Ref. 3 (P) and results from this work (TW)) are compared in the table of Numerical results for Mn II. Comment: for multiplets 11, 12, 20, 23 i 26, $\Delta S/S$ is larger than -0.6 and the results are not included. Because of large differences as well as shift direction average value of d_m/d_{TW} is not calculated.

CR (2009).

References

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Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2320.42	23	2625.61	5	2740.79	25	2900.15	22
2373.36	10	2639.85	15	2750.13	12	2933.05	2
2507.60	11	2672.58	8	2815.03	20	2939.31	2
2532.78	16	2677.85	15	2816.33	14	2949.21	2
2563.64	6	2684.54	19	2846.04	26	3050.65	21
2565.22	6	2698.99	9	2870.09	24	3441.99	3
2576.10	1	2705.73	4	2885.13	22	3482.90	3
2593.72	1	2707.54	4	2886.67	17	3488.68	3
2605.68	1	2708.45	4	2891.33	22	3495.83	3
2610.20	5	2716.80	7	2892.39	18		
2618.15	5	2724.47	8	2897.07	13		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser with two collinear pulses with interpulse delay of 2 μ s at 1064 nm, 12 ns, 60 mJ Target: Fe-Mn alloy in Ar at atmospheric pressure	Hydrogen Balmer H_{α} Stark halfwidth	Boltzmann plot of six Fe I and four Fe II spectral lines	Plasma observed side-on Abel inversion not performed
2	Nd:YAG laser at 1064 nm, 4.5 ns, 60 mJ Target: glass discs prepared of pure MnO in powder form	Hydrogen Balmer H_{α} Stark halfwidth	Boltzmann plot of seven Mn II spectral lines	Plasma observed side-on Abel inversion not performed

Numerical results for Mn II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_p	w_m/w_{TW}	d_m (Å)	d_m/d_p	d_m/d_{TW}	Acc.	Ref.
1	$4s - 4p$	$a^7S - z^7P^o$		12450	1	0.038	0.44	0.56		+/-	0.08	B, B	2
				13800	1	0.080	0.94	1.24	0.0021			B	1
			2576.10	12450	1	0.040	0.45	0.60		+/-	0.09	B, B	2
			2593.72	13800	1	0.090	1.03	1.40				B	1
				12450	1	0.037	0.41	0.55	0.0024	+/-	0.11	B, B	2
			2605.68										
2	$4s - 4p$	$a^5S - z^5P^o$	2933.05	13800	1	0.065	0.54	0.75	0.0033			B	1
				12450	1	0.061	0.48	0.68				B	2
			2939.31	13800	1	0.075	0.62	0.84				B	1
				12450	1	0.063	0.50	0.68	<			B	2
			2949.21	13800	1	0.075	0.52	0.82	0.001			B	1
				12450	1	0.063	0.41	0.66				B	2
3	$3d^6 - 4p$	$a^5D - z^5P^o$	3441.99	13800	1	0.090		0.72				B	1
			3482.90	13800	1	0.065		0.51				B	1
				12450	1	0.118		0.90			0.69	B, B	2
			3488.68	12450	1	0.110		0.83	0.035		0.70	B, B	2
			3495.83	12450	1	0.113		0.84			0.73	B, B	2
									0.035				
									0.036				

4	$4s - 4p$	$a\ ^5G - z$	2705.73	12450	1	0.056	0.75	<		B	2
		$\ ^5G^o$	2707.54	12450	1	0.044	0.63	0.001		B	2
			2708.45	12450	1	0.048	0.66			B	2
								<			
								0.001			
5	$4s - 4p$	$a\ ^5G - z$	2610.20	12450	1	0.040	0.54		+/-	B, B	2
		$\ ^5H^o$	2618.15	12450	1	0.047	0.63	0.0037	+/-	B, B	2
			2625.61	12450	1	0.047	0.63		+/-	B, B	2
								0.0024			
								0.0014			
6	$4s - 4p$	$a\ ^5G - z$	2563.64	12450	1	0.047	0.56		+/-	B, B	2
		$\ ^5F^o$	2565.22	12450	1	0.036	0.45	0.0010		B	2
								<			
								0.001			
7	$4s - 4p$	$a\ ^5P - z\ ^5F^o$	2716.80	12450	1	0.047	0.59	<		B	2
								0.001			
8	$4s - 4p$	$a\ ^5P - z\ ^5D^o$	2672.58	12450	1	0.045	0.49	<		B	2
			2724.47	12450	1	0.050	0.53	0.001	0.06	B, B	2
								-			
								0.003			
9	$4s - 4p$	$a\ ^5P - z\ ^5S^o$	2698.99	12450	1	0.054	0.59			B	2
10	$4s - 4p$	$a\ ^5P - y$	2373.36	12450	1	0.035	0.57		+/-	B, B	2
		$\ ^5D^o$						0.0040			
11	$3d^6 - 4p$	$a\ ^3H - z$	2507.60	12450	1	0.068				B, B	2
		$\ ^3G^o$						0.027			
12	$3d^6 - 4p$	$a\ ^3F - z\ ^3F^o$	2750.13	12450	1	0.064				B, B	2
								0.018			
13	$4s - 4p$	$b\ ^5D - z$	2897.07	12450	1	0.057	0.63			B	2
		$\ ^5D^o$									
14	$4s - 4p$	$b\ ^5D - y$	2816.33	12450	1	0.058	0.68			B	2

		$^5P^o$									
15	$4s - 4p$	$b\ ^5D - y$	2639.85	12450	1	0.044	0.50		+/-	B, B	2
		$^5F^o$	2677.85	12450	1	0.045	0.48	0.0020		B	2
16	$4s - 4p$	$b\ ^5D - y$	2532.78	12450	1	0.043	0.54			B	2
		$^5D^o$									
17	$4s - 4p$	$a\ ^3G - z$	2886.67	12450	1	0.063	0.56		+/-	B, B	2
		$^3H^o$						0.0090			
18	$4s - 4p$	$a\ ^3G - z$	2892.39	12450	1	0.061	0.55		+/-	B, B	2
		$^3F^o$						0.0090			
19	$4s - 4p$	$a\ ^3G - z$	2684.54	12450	1	0.055	0.57		+/-	B, B	2
		$^3G^o$						0.0090			
20	$3d^6 - 4p$	$b\ ^3G - z$	2815.03	12450	1	0.069				B, B	2
		$^3G^o$						0.018			
21	$4s - 4p$	$b\ ^3P - z\ ^3P^o$	3050.65	12450	1	0.066	0.53	-	0.05	B, B	2
								0.003			
22	$4s - 4p$	$b\ ^3P - z$	2885.13	12450	1	0.070	0.59			B	2
		$^3D^o$	2891.33	12450	1	0.058	0.50		+/-	B, B	2
			2900.15	12450	1	0.059	0.50	0.0040	+/-	B, B	2
								0.0010			
23	$3d^6 - 4p$	$a\ ^1I - z\ ^1I^o$	2320.42	12450	1	0.057				B, B	2
								0.019			
24	$4s - 4p$	$b\ ^1I - z\ ^1K^o$	2870.09	12450	1	0.069	0.59	<		B	2
								0.001			
25	$4s - 4p$	$b\ ^3F - z\ ^1F^o$	2740.79	12450	1	0.053	0.34			B	2
26	$4s - 4p$	$c\ ^3G - x$	2846.04	12450	1	0.054				B	2
		$^3H^o$									
The average ratio values							0.58	0.65			

In Ref. 2 the authors report, for every spectral line, only one Stark parameter for temperature interval 11000 – 13900 K.

In this Table the average temperature value of 12450 K is given.

Molybdenum

Mo I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^5 5s^1 S_3$

Ionization energy: $7.09243 \text{ eV} = 57\,204.3 \text{ cm}^{-1}$

Pure molybdenum plasma induced by Nd:YAG laser is used as a light source for the study of Stark broadening parameters of Mo I spectral lines. Plasma observation is carried out side-on and Abel inversion procedure applied. The self-absorption test is applied to check whether studied lines are optically thin and applicable for Stark broadening parameter determination.

The description of used equipment, data about plasma electron density diagnostics with He I 3888.65 Å and wavelength separation of two peaks of He I 4471.48 Å line are used. Finally, details of the electron temperature measurement using Saha-Boltzmann equation are described in the table Key data on experiments.

The experimental Stark widths and the ratio experimental versus semiclassical Stark broadening calculations, performed in this work (TW) only, one can find in the table of Numerical results for Mo I.

Reference

¹D. Dojić, M. Skočić, S. Bukvić, S. Djeniže, J. Phys. B: At. Mol. Opt. Phys. **53**, 075001 (2020).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
4062.08	6	4288.63	2	4536.80	11	4819.25	8
4069.88	6	4293.22	2	4626.46	1	4830.51	8
4185.82	10	4434.95	4	4707.25	9	5059.87	7
4188.32	5	4449.74	3	4731.44	9		
4232.59	5	4457.35	4	4760.18	9		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 532 nm with duration pulse of 5 ns and repetition rate of 1 Hz Target: high purity flat molybdenum sample Plasma generated in the chamber with helium as buffer gas at pressures between 0.1 and 220 mbar	Stark halfwidth of He I 3888.65 Å spectral line and peak separation of He I 4471.48 Å line	Boltzmann plot of 16 Mo I and 4 Mo II spectral lines	Plasma observed side-on

Numerical results for Mo I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	Acc.	Ref.
1	$5s^2 - 5p$	a $^5D - y \ ^5P^o$	4626.46	13000	1.54	0.144		C	1
2	$5s^2 - 5p$	a $^5D - z \ ^5F^o$	4288.63	13000	1.54	0.082		C	1
			4293.22	13000	1.54	0.099		C	1
3	$5s - 5p$	a $^5G - y \ ^5D^o$	4449.74	13000	1.54	0.122	0.84	C	1
4	$5s - 5p$	a $^5G - z \ ^5G^o$	4434.95	13000	1.54	0.180	1.58	C	1
			4457.35	13000	1.54	0.110	0.99	C	1
5	$5s - 5p$	a $^5G - z \ ^5H^o$	4188.32	13000	1.54	0.132	1.30	C	1
			4232.59	13000	1.54	0.131	1.26	C	1
6	$5s - 5p$	a $^5G - y \ ^5F^o$	4062.08	13000	1.54	0.096	0.98	C	1
			4069.88	13000	1.54	0.158	1.57	C	1
7	$5s - 5p$	b $^5D - y \ ^5D^o$	5059.87	13000	1.54	0.184	1.15	C	1
8	$5s - 5p$	a $^3G - y \ ^3F^o$	4819.25	13000	1.54	0.166	1.04	C	1
			4830.51	13000	1.54	0.207	1.36	C	1
9	$5s - 5p$	a $^3G - z \ ^3H^o$	4707.25	13000	1.54	0.226	1.01	C	1
			4731.44	13000	1.54	0.211	0.92	C	1
			4760.18	13000	1.54	0.254	1.24	C	1
10	$5s - 5p$	a $^3I - y \ ^3I^o$	4185.82	13000	1.54	0.151		C	1
11	$5s - 5p$	a $^1I - z \ ^3K^o$	4536.80	13000	1.54	0.203		C	1
The average ratio values							1.17		

Molybdenum

Mo II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^5 \ ^6S_{5/2}$

Ionization energy: 16.16 eV = 130 300 cm⁻¹

Two Nd:YAG lasers are used to induce two separate experiments to determine large number of Stark broadening parameters of Mo II spectral lines.^{1,2} For the target for both experiments pure molybdenum is used. All other experimental details, plasma electron density and temperature diagnostics are described in the table of Key data on experiments. The plasma is observed side-on with the Abel procedure performed and self-absorption test applied to determine whether studied lines are optically thin and applicable for Stark broadening parameter determination.

The transition and multiplet data, presented in the table of Numerical results, are derived from NIST energy levels data³ while in Ref. 1 and Ref 2. same are taken from the Ref. 4. The w_m/w_{TW} ratio was not given in the table of Numerical results because the $\Delta S/S$ is more negative than -0.6.

References

¹D. Dojić, M. Skočić, S. Bukvić, S. Djeniže, J. Phys. B: At. Mol. Opt. Phys. **53**, 075001 (2020).

²D. Dojić, M. Skočić, S. Bukvić, S. Djeniže, J. Quant. Spectrosc. Radiat. Transfer. **248**, 106997 (2020).

³NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

⁴A. N. Zajdelj, V. K. Prokofijev, S. M. Rajskij, V. A. Slavnij, E. Y. Srejder, Spectral Lines Tables, Moscow, Nauka, (1977).

Finding list

Waveleng th (Å)	No.	Waveleng th (Å)	No.	Waveleng th (Å)	No.	Waveleng th (Å)	No.
2777.90	6	2944.86	26	3422.79	17	3861.30	25
2785.02	2	2963.82	5	3435.40	19	3941.50	9
2807.80	6	2968.80	15	3484.58	30	3961.52	9
2866.73	2	2971.95	12	3501.95	19	3986.17	9
2872.93	14	2972.65	1	3651.12	4	4119.64	11
2879.08	20	3023.33	27	3670.68	3	4122.36	29
2903.09	12	3271.69	8	3692.66	7	4209.65	10
2909.14	5	3313.66	16	3702.56	7	4244.75	29
2911.95	5	3329.25	8	3755.51	7	4250.69	10
2927.57	18	3346.43	8	3782.10	22	4279.03	10
2934.34	5	3363.03	17	3783.19	23	4363.65	10
2940.15	13	3371.72	28	3786.39	21	4377.78	10
2941.25	18	3402.82	24	3857.22	9	4433.51	10

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 532 nm with pulse duration of 5 ns and repetition rate of 1 Hz Target: high purity flat molybdenum sample Plasma generated in the vacuum chamber with helium as buffer gas at pressures between 0.1 and 220 mbar	Stark halfwidth of He I 3888.6 Å spectral line and peak separation of He I 4471.5 Å line	Boltzmann plot of 16 Mo I and 4 Mo II spectral lines	Plasma observed side-on
2	Nd:YAG laser EXSPLA NL311-SH-TH at 532 nm with pulse duration of 5 ns and repetition rate of 1 Hz Target: high purity flat molybdenum sample Plasma generated in the chamber with helium as buffer gas at pressures between 0.1 and 220 mbar	Stark halfwidth of He I 3888.6 Å spectral line	Boltzmann plot of 18 Mo I and 4 Mo II spectral lines	Plasma observed side-on

Numerical results for Mo II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	Acc.	Ref.
1	$4d^5 - 5p$	a $^4D - z$ $^6D^o$	2972.65	13000	1.54	0.196		C ⁺	2
2	$4d^5 - 5p$	a $^4D - z$ $^4F^o$	2785.02 2866.73	13000 13000	1.54 1.54	0.246 0.216		C ⁺ C ⁺	2 2
3	$4d^5 - 5p$	a $^4F - z$ $^4F^o$	3670.68	13000	1.54	0.182		C ⁺	2
4	$4d^5 - 5p$	a $^2F - z$ $^4F^o$	3651.12	13000	1.54	0.175		C ⁺	2
5	$5s - 5p$	a $^6D - z$ $^6F^o$	2909.14 2911.95 2934.34 2963.82	13000 13000 13000 13000	1.54 1.54 1.54 1.54	0.193 0.221 0.198 0.153	1.60 1.91 1.56 1.37	C ⁺ C ⁺ C ⁺ C ⁺	2 2 2 2
6	$5s - 5p$	a $^6D - z$ $^4P^o$	2777.90 2807.80	13000 13000	1.54 1.54	0.182 0.205	1.26 1.38	C ⁺ C ⁺	2 2
7	$5s - 5p$	b $^4D - z$ $^4F^o$	3692.66 3702.56 3755.51	13000 13000 13000	1.54 1.54 1.54	0.160 0.194 0.201	0.60 0.70 0.86	C ⁺ C ⁺ C ⁺	2 2 2
8	$5s - 5p$	b $^4D - z$ $^4D^o$	3271.69 3329.25 3346.43	13000 13000 13000	1.54 1.54 1.54	0.166 0.163 0.219	0.85 0.80 1.11	C ⁺ C ⁺ C ⁺	2 2 2
9	$5s - 5p$	b $^4D - z$ $^6D^o$	3857.22 3941.50 3961.52 3986.17	13000 13000 13000 13000	1.54 1.54 1.54 1.54	0.156 0.166 0.206 0.208	0.52 0.52 0.64 0.64	C C C C	1 1 1 1
10	$5s - 5p$	b $^4D - z$ $^4P^o$	4209.65 4250.69 4279.03 4363.65 4377.78 4433.51	13000 13000 13000 13000 13000 13000	1.54 1.54 1.54 1.54 1.54 1.54	0.170 0.199 0.210 0.192 0.197 0.208	0.53 0.56 0.61 0.53 0.53 0.57	C C C C C C	1 1 1 1 1 1
11	$5s - 5p$	b $^4D - z$ $^6P^o$	4119.64	13000	1.54	0.193	0.56	C	1
12	$5s - 5p$	a $^4H - z$ $^4I^o$	2903.09 2971.95	13000 13000	1.54 1.54	0.183 0.137	1.30 0.92	C ⁺ C ⁺	2 2
13	$5s - 5p$	a $^4H - z$ $^4G^o$	2940.15	13000	1.54	0.181	0.85	C ⁺	2
14	$5s - 5p$	b $^4P - y$ $^4P^o$	2872.93	13000	1.54	0.190	1.05	C ⁺	2

Neon

Ne II

Ground state: $1s^2 2s^2 2p^5 {}^2P^{\circ}_{3/2}$

Ionization energy: $40.96297 \text{ eV} = 330\,388.6 \text{ cm}^{-1}$

Two gas discharge experiments^{1,2} are set up and carried out for the measurement of Stark broadening parameters of Ne II lines. In both cases similar equipment and plasma diagnostic technique are used, see Key data on experiments. Here, from the point of view of equipment we draw attention to Ref. 1 which describes details of equipment for typical experiment of this kind with gas discharge used as plasma source, see Fig 1 in Ref. 1 Before the line shape of Ne II lines are studied, the influence of self-absorption to the profile of Ne II lines is carefully investigated in both experiments as well as shape of instrumental profile. The experimental Stark widths and shifts are compared with SC data evaluated from Ref. 3 (G) and this work (TW). The average value of d_m/d_{TW} is not given because of large variation and disagreement of shift orientation in some cases. Theoretical halfwidths from Ref. 4 (D) are compared also. All comparisons experiment versus SC theory one can find in the table Numerical resulted for Ne II lines.

CR (1984, 90, 02, 09).

References

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- ²R. J. Peláez, S. Djurović, M. Ćirišan, J. A. Aparicio, S. Mar, *Opt. Pura. Appl.* **44**, 553 (2011).
- ³H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
- ⁴M. S. Dimitrijević, *J. Appl. Spectrosc.* **70**, 493 (2003).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2792.02	7	3037.72	4	3198.59	11	3327.15	1
2794.22	7	3039.59	14	3209.36	13	3329.16	10
2809.48	7	3044.09	14	3213.74	11	3334.84	1
2872.96	6	3045.56	4	3214.33	11	3344.40	1
2897.00	5	3047.56	4	3218.19	11	3345.45	8
2906.82	6	3054.68	4	3224.82	18	3345.83	8
2910.06	6	3088.16	17	3229.57	18	3367.22	15
2910.41	5	3092.90	19	3230.07	9	3371.80	16
2955.73	2	3094.01	17	3232.37	9	3374.06	10
2963.24	20	3097.13	19	3244.09	12	3378.22	3
2967.18	20	3117.98	13	3297.73	1	3379.32	10
3017.31	4	3164.43	11	3309.74	3	3386.20	10
3027.02	4	3165.65	12	3311.27	1	3390.55	10
3028.86	2	3188.74	11	3319.72	8		
3034.46	4	3190.86	12	3320.20	10		
3035.92	14	3194.58	13	3323.74	3		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Low-pressure pulsed arc operating in gas mixture He(67%) + Ne(33%) at 3 kPa	Two wavelength laser interferometry at 6328 Å and 5130 Å	Boltzmann plot of 39 Ne II Spectral lines	Plasma observed axially end-on
2	Low-pressure pulsed arc operating in gas mixture He(70%) + Ne(30%) at 3 kPa	Two wavelength laser interferometry at 6328 Å and 5130 Å	Boltzmann plot of several Ne II Spectral lines	Plasma observed axially end-on

Numerical results for Ne II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_D	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_D	d_m/d_{TW}	Acc.	Ref.
1	3s - 3p	⁴ P - ⁴ D°		35000	1		1.02	0.98	1.08	$d_1 < 0.015$				B ⁺	1
			3297.73	35000	1	0.1142	1.05	1.01	1.11	$d_1 < 0.015$				B ⁺	1
			3311.27	35000	1		1.10	1.06	1.13	$d_1 < 0.015$				B ⁺	1
			3327.15	35000	1	0.1187	1.02	0.98	0.98	$d_1 < 0.015$				B ⁺	1
			3334.84	35000	1	0.1259	1.02	0.98	1.02	$d_1 < 0.015$				B ⁺	1
			3344.40			0.1168									
2	3s -	⁴ P -	2955.73	35000	1	0.1183									
						0.1078		1.10	1.09					B ⁺	1

3	3 <i>p</i>	⁴ S ^o	3028.86	35000	1	0.1161	1.13	1.10				B	1
	3 <i>s</i> -	² P -	3309.74	35000	1	0.1375	1.09	1.10	<i>d</i> < 0.015			B	1
	3 <i>p</i>	² P ^o	3323.74	35000	1	0.1180	0.93	0.89	<i>d</i> < 0.015			B ⁺	1
4			3378.22	35000	1	0.1290	0.98	0.93	<i>d</i> < 0.015			B ⁺	1
	3 <i>p</i> -	⁴ P ^o -	3017.31	35000	1	0.1456	1.11	1.03	0.0292	1.26	0.79	B, B ⁺	1
	3 <i>d</i>	⁴ D	3027.02	35000	1	0.1492	1.36	1.03	0.0318	1.64	1.07	B ⁺ ,	1
			3034.46	35000	1	0.1531	1.38	1.01	0.0351	1.72		B ⁺	1
			3037.72	35000	1	0.1465	1.32	0.99	0.0366	1.87	1.57	B, B ⁺	1
			3045.56	35000	1	0.1490	1.34	1.00	0.0301	1.53	1.60	B, B ⁺	1
			3047.56	35000	1	0.1481	1.32	0.98	0.0377	1.91	2.05	B ⁺ ,	1
			3054.68	35000	1	0.1496	1.33	1.00	0.0309	1.56	1.23	B ⁺	1
												B ⁺ ,	
5	3 <i>p</i> -	⁴ P ^o -	2897.00	26800	1.61	0.21		1.00				B	2
	3 <i>d</i>	⁴ F	2910.41	26800	1.55	0.22		1.06				B	2
6	3 <i>p</i> -	⁴ P ^o -	2872.96	31000	1.73	0.23		0.78				B	2
	3 <i>d</i>	⁴ P	2906.82	29400	1.62	0.23		0.81				B	2
7			2910.06	26800	1.55	0.21		0.78				B	2
	3 <i>p</i> -	⁴ P ^o -	2792.02	26800	1.60	0.38	1.11	0.86				B ⁺	2
	4 <i>s</i>	⁴ P	2794.22	26800	1.60	0.39	1.14	0.86				B ⁺	2
			2809.48	26800	1.58	0.38	1.11	0.86				B ⁺	2
8	3 <i>s</i> -	² D -	3319.72	35000	1	0.1618		1.34				B	1
	3 <i>p</i>	² P ^o	3345.45	35000	1	0.1619		1.32				B	1
			3345.83	35000	1	0.1647		1.38				B	1
9	3 <i>s</i> -	² D -	3230.07	35000	1	0.1165		1.00	<i>d</i> < 0.015			B	1
	3 <i>p</i>	² D ^o	3232.37	35000	1	0.1268		1.09	<i>d</i> < 0.015			B	1
10	3 <i>p</i> -	⁴ D ^o -	3320.20	35000	1	0.1553		0.84				B	1
	3 <i>d</i>	⁴ D	3329.16	35000	1	0.1447		0.77	0.0395		+/-	B, B ⁺	1
			3374.06	35000	1	0.1259		0.65	0.0308		+/-	B, B ⁺	1

11	3p - 3d	4D° - 4F	3379.32	35000	1				0.0318		+/-	B+	1
			3386.20	35000	1				0.0452		+/-	B+	1
			3390.55	35000	1	0.1329		0.69				B+	1
			3164.43	35000	1				0.0276	0.53	+/-	B+	1
			3188.74	35000	1	0.1672	1.23	1.09	0.0342	0.65	+/-	B, B+	1
			3198.59	35000	1	0.1700	1.24	1.07	0.0340	0.64	+/-	B+,	1
			3213.74	35000	1	0.1877	1.36	1.13	0.0373	0.70	+/-	B+	1
			3214.33	35000	1	0.1780	1.29	1.08	0.0331	0.62	+/-	B, B+	1
			3218.19	35000	1	0.1667	1.20	1.00	0.0358	0.67	+/-	B, B+	1
12	3p - 3d	4D° - 2F	3165.65	35000	1				0.0375		+/-		1
			3190.86	35000	1	0.1629		0.95				B+	1
			3244.09	35000	1	0.1930		1.07	0.0349		+/-	B B+, B+	1
13	3p - 3d	4D° - 4P	3117.98	35000	1	0.1900		1.36	0.0334		+/-	B, B+	1
			3194.58	35000	1	0.1772		1.20	0.0410		+/-	B, B+	1
			3209.36	35000	1				0.0393		+/-	B+	1
14	3p - 4s	4D° - 4P	3035.92	35000	1	0.3195	1.34	0.98				B	1
			3039.59	35000	1	0.2716	1.13	0.85				B	1
			3044.09	35000	1	0.2994	1.24	0.90				B	1
15	3p - 3d	2D° - 4F	3367.22	35000	1	0.1474		0.73				B	1
16	3p - 3d	2D° - 4P	3371.80	35000	1	0.1876		1.10				B	1
17	3p - 4s	2D° - 2P	3088.16	35000	1	0.3096		0.90				B	1
			3094.01	35000	1	0.3263		0.99				B	1
18	3p - 3d	2F° - 2G	3224.82	35000	1	0.1780		1.09	0.0404			B, B+	1
			3229.57	35000	1	0.1606		0.98	0.0406			B, B+	1
19	3p -	2F° -	3092.90	35000	1	0.1635		0.93	0.0387		7.79	B+,	1

	<i>3d</i>	² F	3097.13	35000	1	0.1576		0.89	0.0387		8.18	B ⁺	1
												B ⁺ ,	
												B ⁺	
20	<i>3p</i> -	² F ^o -	2963.24	35000	1	0.3004		0.99				B	1
	<i>4s</i>	² D	2967.18	35000	1	0.2875		0.94				B ⁺	1
	The average ratio values					1.22	1.08	1.00		1.18			

Nickel

Ni II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9 \ ^2D_{5/2}$

Ionization energy: $18.168838 \text{ eV} = 146\,541.56 \text{ cm}^{-1}$

Three experiments¹⁻³ with plasma induced by laser radiation in front of solid target are performed to measure Stark broadening parameters of Ni II lines, see Key data on experiments. In all three experiments care is taken to test line shapes of studied Ni II lines to check whether self-absorption is present. Only optically thin lines or those close to this condition are recorded, analyzed and compared with results of SC calculations. The comparison experiment versus SC results is carried out with theoretical data from Refs. 4 (D) and data evaluated in this work (TW), see table of Numerical results for Ni II. The line wavelengths, transitions arrays and multiplets, for the lines which do not exist in NIST Database⁵, are taken from Ref. 2 and Ref. 3.

Comment: The average data of the ratio experiment versus theory is not given in case of multiplet M4 because $\Delta S/S > 0$. For the multiplets from M13 to M33 there is no comparison between experiment and theory because of the lack of energy level data in NIST Tables⁵.

CR (2002).

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¹R. Mayo, M. Ortiz, M. Plaza, J. Phys. B: At. Mol. Opt. Phys. **41**, 095702 (2008).

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³C. Aragón, J. A. Aguilera, J. Manrique, J. Quant. Spectrosc. Radiat. Transfer **134**, 39 (2014).

⁴M. S. Dimitrijević, Astron. Astrophys. Suppl. Ser. **114**, 171 (1995).

⁵NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2004.27	17	2188.04	2	2305.24	15	2455.52	7
2019.03	18	2201.41	3	2307.78	15	2497.80	7
2020.98	18	2206.72	3	2308.52	27	2510.87	7
2032.30	22	2210.38	3	2316.04	1	2539.10	25
2033.39	4	2213.20	32	2318.51	20	2545.90	7
2053.29	4	2216.48	2	2334.58	9	2551.03	6
2080.85	5	2220.40	12	2341.21	27	2557.87	24
2084.87	22	2222.96	2	2343.49	31	2584.00	25
2090.10	4	2226.33	2	2356.40	11	2630.28	6
2097.10	16	2247.23	32	2366.54	14	2648.72	6
2103.39	16	2253.85	2	2367.38	1	2670.32	23
2107.95	33	2264.46	2	2369.22	14	2760.67	29
2113.52	33	2270.21	2	2375.42	10	2805.67	28
2125.91	3	2275.68	32	2387.76	8	2808.35	13
2128.58	4	2277.28	31	2392.58	14	2842.41	28
2138.58	3	2278.77	11	2405.17	26	2863.69	30
2158.74	3	2287.08	11	2410.75	7	2947.45	13
2165.55	3	2287.65	20	2413.04	8	2988.06	19
2169.10	3	2296.55	10	2416.13	9		
2184.60	3	2299.65	14	2433.56	8		
2185.50	21	2300.10	14	2437.89	8		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm, 200 mJ, 7 ns, 20 Hz Target: Al-Ni alloy in argon filling gas at 6.5 Torr	Halfwidth of Al II 2816.19 Å spectral line	Boltzmann plot of Ni II spectral lines	Plasma observed side-on Abel inversion not performed
2	Nd:YAG at laser 1064 nm, 100 mJ, 4.5 ns, 20 Hz Target: Ni-Cu and Ni-Al alloys with of 5% of Fe Plasma induced in air at atmospheric pressure	Halfwidth of the H _α spectral line	Boltzmann plot of eight Fe II Spectral lines	Plasma observed side-on Abel inversion not performed
3	Nd:YAG laser at 1064 nm, 300 mJ, 4.5 ns, repetition rate 20 Hz Target: borate fusion of Fe ₂ O ₃ and NiO oxides in powder form Plasma induced in air at atmospheric pressure	Halfwidth of the H _α spectral line	Boltzmann plot of Fe II spectral lines	Plasma observed side-on Abel inversion not performed

Numerical results for Ni II

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron		w_m (Å)	w_m/w_D	w_m/w_{TW}	Acc.	Ref
					density (10^{17} cm^{-3})						
1	$(^3F)4s - (^3F)4p$	$^4F - ^4D^o$	2316.04	15500	1	0.034			0.73	B	2
			2367.38*	15500	1	0.028			0.59	B	2
2	$(^3F)4s - (^3F)4p$	$^4F - ^4G^o$	2188.04*	15500	1	0.030			0.75	B	2
			2216.48	16500	0.55	0.042			1.79	B	1
				14800	1	0			0.77	B	3
			2222.96	16500	0.55	0.034			2.25	B	1
				15500	1	0.050			0.72	B	2
			2226.33*	16500	0.55	5			2.04	B	1
				14800	1	0.030			0.70	B	3
			2253.85	16500	0.55	0.046			2.20	B	1
				15500	1	6			0.76	B	2
			2264.46	16500	0.55	0.030	1.77		2.32	B	1
				14800	1	0.052	0.59		0.78	B	3
			2270.21	16500	0.55	9	1.76		2.28	B	1
				15500	1	0.034	0.50		0.66	B	2
						0.055					
						3					
						0.035					
						0.054					
						4					
						0.029					
3	$(^3F)4s - (^3F)4p$	$^4F - ^4F^o$	2125.91*	14800	1	0.031			0.78	B	3
			2138.58*	14800	1	0.028			0.69	B	3
			2158.74*	15500	1	0.035			0.86	B	2
			2165.55	15500	1	0.035			0.84	B	2
			2169.10	16500	0.55	0.046			2.06	B	1
				15500	1	3			0.72	B	2
			2184.60	15500	1	0.030			0.74	B	2
			2201.41	16500	0.55	0.032			2.72	B	1
			2206.72	16500	0.55	0.063			2.58	B	1
				15500	1	6			0.78	B	2
			2210.38*	16500	0.55	0.060			2.28	B	1
				14800	1	6			0.71	B	3
						0.034					
						0.052					
						6					
						0.031					
4	$(^3F)4s - (^3F)4p$	$^4F - ^3F^o$	2333.33*	15500	1	0.035				B	2

*The lines which appear in NIST Tables are only Ritz wavelength

**The lines which do not exist in NIST Tables.

Oxygen

O I

Ground state: $1s^2 2s^2 2p^4 \ ^3P_2$

Ionization energy: $13.618055 \text{ eV} = 109\,837.02 \text{ cm}^{-1}$

Two experiments are set-up to measure Stark broadening parameters of O I multiplet $3s^5S^o - 3p^5P$ lines.^{1,2} Both experiments used laser induced plasma as a light source. For the first experiment target is fused silica while for the second one pellet is used, see Key data on experiments, where one can find basic details about used plasma sources and plasma diagnostics. The most important details of Ref. 1 one can find in report for Ba II, while for experiment described in Ref. 2 is in report for Ca I. For both experiments self-absorption test is carried out for all lines before halfwidths are measured. Only if line is optically thin or if may be corrected for minor self-absorption is recorded and Stark parameter determined.

The experimental results for O I Stark broadening parameters one can find in the table Numerical results for O I, where they are compared with SC results evaluated from Ref. 3 (G) and data calculated within this work (TW). Here it should be mentioned that considerable discrepancy between ratios d_m/d_G and d_m/d_{TW} exists.

CR (1976, 90, 02).

References

- ¹C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet, M. Sentis, W. Viöl, *Spectrochim. Acta B* **101**, 32 (2014).
- ²M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).
- ³H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone
2	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer the H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for O I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{TW}	Acc.	Ref.
1	3s - 3p	$^5S^o - ^5P$	7771.94	11200	1	0.64	0.94	0.78	0.14	0.94	0.14	C ⁺ ,	1
				11000	1	1.05	1.56	1.29	0.15	1.00	0.15	C ⁺	2
			7774.17	11000	1	1.05	1.56	1.31	0.15	1.00	0.14	C ⁺ , C	2

7775.39	11000	1	1.05	1.56	1.31	0.15	1.00	0.14	C ⁺ , C	2
									C ⁺ , C	

Stark shift are measured and compared with both sets of SC calculations at the peak of line profile.

Oxygen

O II

Ground state: $1s^2 2s^2 2p^3 \ ^4S^{\circ}_{3/2}$

Ionization energy: $35.12112 \text{ eV} = 283\,270.9 \text{ cm}^{-1}$

The electromagnetically driven T- tube is used as a plasma source for the measurement of Stark broadening parameters of O II lines¹, for experimental details and plasma diagnostics see Key data on experiment. The self-absorption test is always carried out before Stark halfwidth is measured. The comparison experiment versus SC calculations is performed against three sets of calculations: Ref. 2 (G), Ref. 3 (M) and data evaluated in this work (TW), see table of Numerical results for O II.

Comments in relation to multiplets 1, 2, 3, 16 and 17:

There are some variations of w_m/w_{TW} values within M1, M2 and M3, see table of Numerical results for O II. These variations arise due to differences in perturbing levels which lead to $\Delta S/S$ variations. The ratio w_m/w_G for M1 and M2 shows smaller variation. But it should be mentioned here that some differences between energy levels from NIST Database⁴ and earlier data⁵, used for Griem's calculations², exists. For the data in M16 and M17 sets of perturbing energy levels are not complete ($\Delta S/S < -0.6$).

CR (1976, 90, 02, 09).

References

- ¹L. Gavanski, M. T. Belmonte, I. Savić, S. Djurović, Month. Not. Roy. Astron. Soc. **457**, 4038 (2016).
- ²H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
- ³W. F. Mahmoudi, N. Ben Nessib, S. Sahal-Brechot, Phys. Scr. **70**, 142 (2004).
- ⁴NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>
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Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
3712.74	3	4089.29	16	4414.91	4	4676.24	1
3727.32	3	4153.30	9	4416.97	4	4703.16	15
3749.49	3	4169.23	9	4590.97	7	4705.35	11
3919.29	8	4185.45	14	4596.18	7	4710.01	10
3945.04	5	4189.79	14	4638.86	1	4871.52	18
3954.36	5	4303.83	17	4641.81	1	4890.86	13
3973.26	5	4345.56	2	4649.14	1	4924.53	13
3982.71	5	4349.43	2	4650.84	1		
4072.16	6	4359.39	12	4661.63	1		
4085.11	6	4366.89	2	4673.73	1		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Electromagnetically driven T-tube filled with pure helium at the pressure of 300 Pa.	The separation between two peaks of He I 4471.5 Å spectral line	Boltzmann plot of six Si II and twelve O II spectral lines	Plasma observed side-on

Numerical results for O II

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m /w _G	w _m /w _M	w _m /w _{TW}	Acc.	Ref
1	3s - 3p	⁴ P - ⁴ D ^o	4638.86	15000	1.45	0.501	0.95		1.07	B ⁺	1
			4641.81	15000	1.45	0.510	0.96		0.74	B ⁺	1
			4649.14	15000	1.45	0.507	0.96		1.00	B ⁺	1
			4650.84	15000	1.45	0.523	0.98		1.12	B ⁺	1
			4661.63	15000	1.45	0.532	1.00		0.77	B ⁺	1
			4673.73	15000	1.45	0.540	1.01		0.77	B ⁺	1
			4676.24	15000	1.45	0.549	1.02		1.151	B ⁺	1
2	3s - 3p	⁴ P - ⁴ P ^o	4345.56	15000	1.45	0.428	1.10	0.86	0.70	B	1
			4349.43	15000	1.45	0.420	1.08	0.84	0.94	B	1
			4366.89	15000	1.45	0.426	1.09	0.84	0.97	B	1
3	3s - 3p	⁴ P - ⁴ S ^o	3712.74	15000	1.45	0.411		1.34	1.21	B ⁺	1

			3727.32	15000	1.45	0.412		1.34	0.87	B ⁺	1
			3749.49	15000	1.45	0.409		1.31	1.14	B ⁺	1
4	3s - 3p	² P - ² D ^o	4414.91	15000	1.45	0.467	1.01	0.86	0.99	B ⁺	1
			4416.97	15000	1.45	0.442	0.96	0.81	0.93	B ⁺	1
5	3s - 3p	² P - ² P ^o	3945.04	15000	1.45	0.367	1.01	0.85	0.95	B ⁺	1
			3954.36	15000	1.45	0.368	1.01	0.85	0.94	B ⁺	1
			3973.26	15000	1.45	0.415	1.13	0.95	1.04	B ⁺	1
			3982.71	15000	1.45	0.412	1.12	0.94	1.05	B ⁺	1
6	3p - 3d	⁴ D ^o - ⁴ F	4072.16	15000	1.45	0.480	1.12	0.91	1.02	B	1
			4085.11	15000	1.45	0.492	1.14	0.93	1.14	B	1
7	3s - 3p	² D - ² F ^o	4590.97	15000	1.45	0.385		0.60	0.78	B ⁺	1
			4596.18	15000	1.45	0.398		0.62	0.80	B ⁺	1
8	3s - 3p	² D - ² P ^o	3919.29	15000	1.45	0.358			0.96	B ⁺	1
9	3p - 3d	⁴ P ^o - ⁴ P	4153.30	15000	1.45	0.540	1.20		1.00	B ⁺	1
			4169.23	15000	1.45	0.545	1.21		1.02	B ⁺	1
10	3p - 3d	² D ^o - ⁴ D	4710.01	15000	1.45	0.686			1.12	B ⁺	1
11	3p - 3d	² D ^o - ² F	4705.35	15000	1.45	0.624	1.01	0.86	0.90	B ⁺	1
12	3p - 3d	² D ^o - ² D	4359.39	15000	1.45	0.583			0.96	B ⁺	1
13	3p - 3d	⁴ S ^o - ⁴ P	4890.86	15000	1.45	0.751		1.16	1.09	B ⁺	1
			4924.53	15000	1.45	0.762		1.16	1.05	B ⁺	1
14	3p - 3d	² F ^o - ² G	4185.45	15000	1.45	0.442		0.73	0.84	B ⁺	1
			4189.79	15000	1.45	0.460		0.76	0.87	B ⁺	1
15	3p - 3d	² D ^o - ² F	4703.16	15000	1.45	0.681			0.97	B ⁺	1
16	3d - 4f	⁴ F - ² [5] ^o	4089.29	15000	1.45	1.368				B	1
17	3d - 4f	⁴ P - ² [3] ^o	4303.83	15000	1.45	1.233				B	1
18	3p - 3d	² P ^o - ² D	4871.52	15000	1.45	0.725			1.12	B ⁺	1
The average ratio values							1.05	0.93	0.97		

Potassium

K I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 S_{1/2}$

Ionization energy: $4.34066373 \text{ eV} = 35\,009.8140 \text{ cm}^{-1}$

For details see Report for Ca II
CR (1984, 90)

References

- ¹C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. . Luculescu, T. Sarnet, M. Sentis, W. Viöl, *Spectrochim. Acta B.* **101**, 32 (2014).
²H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
³M. S. Dimitrijević, S. Sahal-Bréchet, J. Quant. Spectrosc. Radiat, Transfer **38**, 37 (1987).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone

Numerical results for K I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{DS}	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	4s - 4p	$^2S - ^2P^o$	7698.96	11200	1	0.72	0.80	1.21	0.70	0.24	0.73	0.47	0.21	C ⁺ , C ⁺	1

Silicon

Si I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^2 \ ^3P_0$

Ionization energy: $8.15168 \text{ eV} = 65\,747.76 \text{ cm}^{-1}$

Three experiments¹⁻³ are selected, and results analyzed to derive Stark broadening parameters of Si I lines. First experiment uses linear, low pressure, discharge Pyrex glass tube (12cm long and 5 mm internal diameter) as a light source. Pulsed electrical discharge is generated in the mixture of gases with silicon introduced in discharge by an ablation of the glass tube wall. The details of plasma source and spectroscopic plasma diagnostics one can find in the table Key data on experiments under Ref.1.

The following two experiments^{2, 3} employ laser induced plasma as a light source. In Ref, 2 plasma observations are performed side-on with Abel inversion procedure. For the third experiment³ plasma observations are carried out end-on under small angle 15° in respect to the incident laser beam, which is used for plasma generation and, which is directed perpendicular to the target surface. Finally, it should be mentioned that in all three experiments¹⁻³ self-absorption test is always carried for all lines used for the Stark broadening parameters determination. Only optically thin or weakly self-absorbed lines, which can be corrected to the optically thin case, are used for Stark parameters measurement.

The temperature values, reported in the table of Numerical results for Refs. 2 and 3, are derived from graphical presentation of plasma diagnostic data, see Fig. 7 in Ref 2 and Fig. 6 in Ref. 3.

The experimental results for Si I Stark halfwidths and shifts and comparisons in the form of ratios of experimental and theoretical data of SC calculations after Griem⁴ (G) and this work (TW) are given in the table of Numerical results for Si I. The calculation w_m/w_{TW} is omitted for multiplet 2 because of incomplete set of perturbing levels. Same difficulty for the line from multiplet 5 occurs as well. In the Ref. 1 transition and multiplet notation is not reported. In the table of Numerical results these data are given according to the NIST Database.⁵ The line in multiplet 7 is introduced as "observed" but no data about energy levels of the transition within NIST Database.⁵ The transition array and multiplet are taken from the tables Striganov and Sventickii.⁶ This line corresponds to the transmission which is given in the table of Numerical_results as well but the upper level of the

transition is above ionization limit in NIST Database⁴ list of energy levels. This is why the comparison with the theory is omitted from the table in this case.

CR (1976, 02).

References

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- ³M. Burger, J. Hermann, *Spectrochim. Acta B* **122**, 118 (2016).
- ⁴H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
- ⁵NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>
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Plenum, New York (1968).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2061.19	7	2506.90	1	2524.11	1	3905.52	6
2207.98	2	2514.32	1	2528.51	1		
2210.89	2	2516.11	1	2881.58	4		
2435.15	5	2519.20	1	2987.65	3		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc Discharges generated in Pyrex tube with discharge gas mixture 90% He + 7% N ₂ + 3% O ₂ at the initial pressure of 665 Pa Silicon was introduced in discharge by sputtering of the glass discharge tube	Stark width of the He II P _α 4686 Å spectral line	Intensity ratio between Si III (3086.2 Å, 3093.4 Å and 3096.8 Å) and Si IV (3149.6 Å and 3165.7 Å) and also between O II 3973.3 Å and O III 3961.6 Å spectral lines	Plasma observed axially end-on
2	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in vacuum chamber filled with argon at 5×10 ⁴ Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and Si II doublet 3856.0 Å, 3862.6 Å spectral lines	Plasma observed side-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone
3	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in vacuum chamber filled with argon at 5×10 ⁴ Pa	Hydrogen Balmer H _α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters determined by the best fit between measured and computed spectra

Numerical results for Si I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{TW}	Acc.	Ref.
1	$3p^2 - 4s$	$^3P - ^3P^o$	2506.90	15000	1	0.141	1.33	1.14				C ⁺	1
				11000	1	0.140	1.42	1.26	0.08	1.34	0.98	B, B	3
			2514.32	15000	1	0.112	1.05	0.92				C ⁺	1
			2516.11	15000	1	0.117	1.09	0.94				C ⁺	1
			2519.20	12500	1	0.112	1.09	0.97				C ⁺	1
			2524.11	12500	1	0.104	1.01	0.91				C ⁺	1
			2528.51	12500	1	0.107	1.03	0.92				C ⁺	1
2	$3p^2 - 3p^3$	$^3P - ^3D^o$	2207.98	12500	1	0.065						C ⁺	1
			2210.89	12500	1	0.061						C ⁺	1
3	$3p^2 - 4s$	$^1D - ^3P^o$	2987.65	15000	1	0.147		0.85				C ⁺	1
4	$3p^2 - 4s$	$^1D - ^1P^o$	2881.58	15000	1	0.145	0.99	0.82				C ⁺	1
5	$3p^2 - 3d$	$^1D - ^1D^o$	2435.15	12500	1	0.125						C ⁺	1
6	$3p^2 - 4s$	$^1S - ^1P^o$	3905.52	12500	1	0.208	0.81	0.68				C ⁺	1
				11200	1	0.310	1.23	1.06	0.16	1.05	0.74	C ⁺ , C ⁺	2
7	$3p^3 - 4s$	$^5S^o - ^5P$	2061.19	15000	1	0.050						C ⁺	1
The average ratio values							1.11	0.95		1.2	0.86		

Silicon

Si II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^2 P^\circ_{1/2}$

Ionization energy: $16.34585 \text{ eV} = 131\,838.14 \text{ cm}^{-1}$

Four experiments¹⁻⁴ are devoted to the studies of Stark broadening parameters of Si II halfwidths and shifts. Short description of experimental details one can find in the table Key data on experiments.

The plasma source in Ref, 1 is made of narrow Pyrex glass tube filled with the mixture of various gases with the dominant contribution of helium. The silicon is introduced in plasma by ablation of the glass walls.

In Ref. 2 excitation of Si II is achieved by pulsing Nd:YAG laser towards rotating cylindrical crystal rod. During side-on plasma observation in Ref, 2 the Abel inversion procedure is applied. In Ref. 2 however, only several lines are symmetric while, the majority of lines are asymmetric.

In Ref. 3 Nd:YAG laser is used in a single pulse regime to induce plasma in front of the target made of fused silica, heavy flint glass and barite crown glass located in the vacuum chamber partially filled with argon. The temperature value reported in the table of Numerical results is derived by using graphical presentation of plasma diagnostic data (Fig. 7 in Ref. 3).

In Ref. 4 electromagnetic shock tube is used as a plasma source, while silicon is introduced in plasma by sputtering of glass wall.

All experimental halfwidths in Refs. 1, 3 and 4 are tested for self-absorption before line halfwidth is used for derivation of Stark broadening parameter. The optically thin lines are used only for Stark broadening parameter determination.

It is important to mention that all recorded Si II lines for Stark broadening parameters measurement in Refs. 1, 3 and 4 have symmetric Lorentz or Voigt profiles, which are characteristic for singly charged ion lines. In Ref. 2 the authors report asymmetrical line profiles, except for the 3991.77 \AA line. These lines show relatively large asymmetry with the ratio of red to blue side of the halfwidth between 1.2 and 4.5 while line 3339.82 \AA shows extremely large asymmetry with the ratio about 20. Most likely the cause of line profile asymmetry is experimental origin although the authors claim that there is no plasma inhomogeneity.

The Si II lines from multiplets M10 to M13 are present in NIST Database⁵ line table, however, the transition and multiplet notation is missing. In the table of Numerical result for Si II the notation is derived from energy levels table of NIST Database.⁵

The comparison experiment versus three SC calculations in Refs. 6 (G) and 7 (L) and in this work (TW), one can find in the table of Numerical results for Si II. For the data M10 - M13 of perturbing energy levels are not complete and the comparison with theory is not given.

CR (1976, 84, 90, 02, 09).

References

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⁷T. Lanz, M. S. Dimitrijević, M. -C. Artru, *Astron. Astrophys.* **192**, 249 (1988).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2072.02	2	3853.66	1	4016.22	12	5669.56	9
2072.70	2	3856.02	1	4128.07	4	5957.56	6
2904.28	5	3862.60	1	4130.89	4	5978.93	6
2905.69	5	3977.46	12	4198.13	10	6347.10	3
3333.14	8	3991.77	11	5041.03	7	6371.36	3
3339.82	8	3998.01	13	5055.98	7		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc Discharge is generated within Pyrex tube filled with gas mixture of 90% He + 7% N ₂ + 3% O ₂ at the pressure of 665 Pa Silicon was introduced in the discharge by sputtering of the glass	Stark width of the He II P _α 4686 Å spectral line	Intensity ratio between Si III (3086.2 Å, 3093.4 Å and 3096.8 Å) and Si IV (3149.6 Å and 3165.7 Å) and the ratio between O II 3973.3 Å and O III 3961.6 Å spectral lines	Plasma observed axially end-on
2	Nd:YAG laser 1064 nm Single pulse 300 mJ, 10 ns Target: silicon cylindrical rod of 5 mm diameter with 99.999% purity Plasma induced in vacuum and in xenon	Hydrogen Balmer_H _α spectral line	Boltzmann plot of nine Xe II spectral lines	Plasma observed side-on
3	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in vacuum chamber filled with argon at 5×10 ⁴ Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed side-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and plasma parameters calculated for each zone
4	Electromagnetically driven T-tube The tube is filled with pure helium at the pressure of 300 Pa.	The separation between allowed and forbidden peaks of He I 4471.5 Å	Boltzmann plot of six Si II and twelve O II	Plasma observed side-on

Silicon is introduced in the
discharge by sputtering of the
tube glass

spectral line

spectral lines

Numerical results for Si II

No.	Trans. array	Mult.	Wavel. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_L	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{TW}	Acc.	Ref.
1	$3p^2 - 4p$	$^2D - ^2P^o$	3853.66	15000	1				0.81				B ⁺	1
				15000	1.45	0.535			0.66				B ⁺	4
			3856.02	15000	1			1.05	0.74				B ⁺	1
				11200	1	0.631		1.09	0.80				C ⁺	3
				15000	1.45			0.99	0.70				B ⁺	4
			3862.60	15000	1	0.490			0.64				B ⁺	1
				11200	1	0.58			0.79				C ⁺	3
				15000	1.45				0.61				B ⁺	4
						0.669								
						0.430								
						0.58								

2	$3p^2 - 4f$	$^2D - ^2F^o$		15600	1	0.589								C ⁺	1
			2072.02	15600	1	0.120				0.46					
			2072.70							0.38					
3	$4s - 4p$	$^2S - ^2P^o$	6347.10	12500	1	0.100								B	1
				15000	1.45	1.85 0.84 1.06 0.94				0.53 0.68 0.59					
			6371.36	12500	1	1.582 0.84 0.96								B	1
				15000	1.45	1.87 0.56 0.64								B ⁺	4
4	$3d - 4f$	$^2D - ^2F^o$		15000	1	1.691								B ⁺	1
				15000	1.45	1.05 0.83 0.87				0.80 0.85					
			4128.07	15000	1	1.482 0.94 1.16 1.00								B ⁺	4
				15000	1.45	1.20 0.81 0.99 0.85								B ⁺	1
			4130.89											B ⁺	4
5	$3d - 5f$	$^2D - ^2F^o$	2904.28	15600	1	1.487								B	1
			2905.69	15600	1	3.11 1.23 1.27				3.49 1.38 1.42					
6	$4p - 5s$	$^2P^o - ^2S$	5957.56	12500	1	2.92 1.18 1.00								B	1
			5978.93	12500	1	2.76 1.11 1.07 0.94									
7	$4p - 4d$	$^2P^o - ^2D$	5041.03	15000	1	2.29 0.83 0.85								B	1
				5055.98	15000	1	2.50 0.90 1.23 0.93								
				15000	1.45	2.93 0.73 0.99 0.75								B ⁺	4
8	$4p - 6s$	$^2P^o - ^2S$	3333.14	14000	1.70	7.79 2.39 2.27 0.22 0.12 0.12								D, D	2
				15000	2.78	8.16 1.54 1.45 0.01 0.003 0.003									
				16000	3.85	8.00 1.09 1.03 0.25 0.06 0.06								D, D	2
				17000	4.93	9.52 1.02 0.95 0.20 0.04 0.04								D, D	2
				18000	6.00	10.36 0.91 0.85 1.15 0.19 0.18								D, D	2
			3339.82	14000	1.70	6.30 1.93 2.30 1.83 0.65 0.36 0.34								D, D	2
				15000	2.78	6.84 1.28 1.55 1.21 0.62 0.21 0.20								D, D	2

				16000	3.85	8.59	1.17	1.43	1.10	0.66	0.16	0.15	D, D	2
				17000	4.93	7.92	0.84	1.04	0.79	0.45	0.09	0.08	D, D	2
				18000	6.00	9.54	0.84	1.04	0.78	0.56	0.09	0.09	D, D	2
9	(³ P ^o)3 <i>d</i> – (³ P ^o)4 <i>p</i>	⁴ F ^o – ⁴ D	5669.56	15000	1.45	0.943			1.01				B	4
10	(³ P ^o)3 <i>d</i> – (³ P ^o)4 <i>p</i>	² D ^o – ² P	4198.13	15000	1.45	0.144							B ⁺	4
11	(³ P ^o)3 <i>d</i> – (³ P ^o)4 <i>fG</i>	² F ^o – ² [5]	3991.77	14000	1.70	5.64				0.17			D, D	2
				15000	2.78	6.32				0.06			D, D	2
				16000	3.85	7.30				0.02			D, D	2
				17000	4.93	8.02				0.09			D, D	2
				18000	6.00	6.20				0.04			D, D	2
12	(³ P ^o)3 <i>d</i> – (³ P ^o)4 <i>fG</i>	² F ^o – ² [4]	3977.46	14000	1.70	7.23				0.38			D, D	2
				15000	2.78	6.91				0.23			D, D	2
				16000	3.85	7.73				0.28			D, D	2
				17000	4.93	9.01				0.10			D, D	2
				18000	6.00	8.08				0.20			D, D	2
			4016.22	14000	1.70	3.98				0.17			D, D	2
				15000	2.78	4.78				0.04			D, D	2
				16000	3.85	5.70				0.10			D, D	2
				17000	4.93	6.31				0.10			D, D	2
				18000	6.00	6.21				0.60			D, D	2
13	(³ P ^o)3 <i>d</i> – (³ P ^o)4 <i>fG</i>	² F ^o – ² [3]	3998.01	14000	1.70	5.36				0.18			D, D	2
				15000	2.78	5.40				0.79			D, D	2
				16000	3.85	5.29				0.79			D, D	2
				17000	4.93	5.67				0.96			D, D	2
				18000	6.00	6.00				0.02			D, D	2
The average ratio values							1.06	1.18	0.94		0.13	0.13		

Silicon

Si III

Ground state: $1s^2 2s^2 2p^6 3s^2 \ ^1S_0$

Ionization energy: $33.49300 \text{ eV} = 270\,139.3 \text{ cm}^{-1}$

Two experiments^{1, 2} are set up for the study of Stark broadening halfwidths of Si III lines.

The plasma source of Ref, 1 is made of narrow Pyrex glass tube filled with the mixture of various gases with the dominant contribution of helium. The silicon is introduced in plasma by ablation of the Pyrex glass walls.

The electromagnetically driven *T*-tube is used as a plasma source of the second experiment.² The *T*-tube, is made of glass, with an internal diameter of 27 mm, filled with pure helium up to 300 Pa. The distance between the reflector and the electrodes is 140 mm. Silicon is introduced in plasma by sputtering of glass tube.

Before Stark halfwidth is used for derivation of Si III Stark broadening halfwidth the self-absorption test is carried out. Only optically thin Si III lines and lines or lines which can be corrected to optically thin conditions are used for Stark broadening evaluation.

The comparison experiment - versus SC calculations are available with theoretical results of this work (TW) only. In the case of multiplets M7 and M11 where $\Delta S/S < -0.8$, comparison with calculated Stark parameters are not reported.

In the Ref.1 erroneous notation is used for the transition describing 3185.13 Å ($4d \ ^1D - 3d \ ^1P^o$) line from M11 multiplet. Therefore, instead of erroneous transition in the table of Numerical results for Si III is replaced with $4d \ ^1P^o - 5s \ ^1S$ transition in accordance with energy levels from NIST Database.³

CR (1976, 84, 90, 02, 09).

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- ²L. Gavanski, M. T. Belmonte, I. Savić, S. Djurović, *Month. Not. Roy. Astron. Soc.* **457**, 4038 (2016).
- ³NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

Finding list

Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.
2541.82	1	3096.83	2	3590.47	10	4567.82	3
2546.09	7	3185.13	11	3791.41	8	4574.76	3
2559.21	6	3196.50	12	3796.11	8	4716.65	14
2640.79	16	3230.50	9	3806.54	8	4813.33	17
3034.73	18	3233.95	9	3924.47	15	4819.72	17
3086.24	2	3241.62	9	4338.50	4	4828.97	17
3093.42	2	3486.91	13	4552.62	3	5739.73	5

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc Discharge generated within pyrex tube with working gas mixture 90% He + 7% N ₂ + 3% O ₂ at the initial pressure of 665 Pa Silicon is introduced in the working gas by ablation of the pyrex tube walls	Stark width of the He II P _α 4686 Å spectral line	Intensity ratio between Si III lines (3086.2 Å 3093.4 Å and 3096.8 Å) and Si IV (3149.6 Å and 3165.7 Å) and also between O II 3973.3 Å and O III 3961.6 Å spectral lines	Plasma observed axially end-on
2	Electromagnetically driven T- tube filled with pure helium up to pressure of 300 Pa.	Separation of allowed and forbidden component of He I 4471.48 Å line.	Boltzmann plot of six Si II and twelve O II spectral lines	Plasma observed side-on

Numerical results for Si III

No	Trans.	Mult.	Wave.	Temp.	Electron	w_m	w_m/w_{TW}	Acc.	Ref.
.	array		(Å)	(K)	density (10^{17} cm^{-3})	(Å)			
1	$3p - 3p^2$	$^1P^o - ^1D$	2541.82	19000	1	0.065	1.08	B ⁺	1
2	$3d - 4p$	$^3D - ^3P^o$	3086.24	18800	1	0.311	1.33	B ⁺	1
				15000	1.45	0.306	0.84	B ⁺	2
			3093.42	18800	1	0.285	1.22	B ⁺	1
				15000	1.45	0.319	0.88	B ⁺	2
			3096.83	18800	1	0.277	1.19	B ⁺	1
				15000	1.45	0.332	0.92	B ⁺	2
3	$4s - 4p$	$^3S - ^3P^o$	4552.62	19000	1	0.512	0.94	B ⁺	1
				15000	1.45	0.756	0.89	B ⁺	2
			4567.82	19000	1	0.542	1.05	B ⁺	1
				15000	1.45	0.784	0.97	B ⁺	2
			4574.76	19000	1	0.485	1.01	B	1
				15000	1.45	0.791	1.05	B ⁺	2
4	$3p^2 - 4p$	$^1S - ^1P^o$	4338.50	19000	1	0.269	0.46	B	1
5	$4s - 4p$	$^1S - ^1P^o$	5739.73	19000	1	0.982	0.86	B	1
				15000	1.45	1.346	0.76	B ⁺	2
6	$3d - 4f$	$^1D - ^1F^o$	2559.21	19000	1	0.068	0.19	B	1
7	$3d - 3d$	$^1D - ^1D^o$	2546.09	19000	1	0.068		B	1
8	$4p - 4d$	$^3P^o - ^3D$	3791.41	18800	1	0.743	1.12	B ⁺	1
				15000	1.45	1.028	1.00	B ⁺	2
			3796.11	18800	1	0.797	1.19	B ⁺	1
				15000	1.45	0.962	0.93	B ⁺	2
			3806.54	18800	1	0.784	1.17	B ⁺	1
				15000	1.45	1.043	1.00	B ⁺	2
9	$4p - 5s$	$^3P^o - ^3S$	3230.50	19000	1	0.433	0.67	B	1
			3233.95	19000	1	0.446	0.69	B	1
			3241.62	19000	1	0.481	0.74	B	1
10	$4p - 4d$	$^1P^o - ^1D$	3590.47	18800	1	0.866	0.74	B	1
				15000	1.45	1.235	0.68	B ⁺	2
11	$4p - 5s$	$^1P^o - ^1S$	3185.13	18800	1	0.277	0.36	B	1
12	$3d - 5g$	$^3F^o - ^3G$	3196.50	18800	1	0.323	0.21	B	1
13	$4d - 5f$	$^3D - ^3F^o$	3486.91	19000	1	0.502	0.19	B	1
14	$4d - 5f$	$^1D - ^1F^o$	4716.65	19000	1	1.810	0.63	B	1
15	$4f - 5g$	$^1F^o - ^1G$	3924.47	19000	1	0.846	0.61	B	1
				15000	1.45	1.719	0.81	B ⁺	2
16	$3d - 4p$	$^1D^o - ^1P$	2640.79	19000	1	0.242		B	1
17	$4f - 5g$	$^3F^o - ^3G$	4813.33	19000	1	3.980	1.12	B	1
			4819.73	19000	1	4.330	1.12	B	1

Silicon

Si IV

Ground state: $1s^2 2s^2 2p^6 3s^2 S^1_{1/2}$

Ionization energy: $45.14179 \text{ eV} = 364\,093.1 \text{ cm}^{-1}$

The plasma source (direct discharge glass tube), experimental procedure and plasma diagnostics used for the measurement of Si IV Stark broadening halfwidths¹ are very similar to the Stark width experiments reported earlier after Si I, Si II and Si III studies by the same group of the authors,¹ see corresponding reports. The only difference may be in discharge energy input and time of plasma observation.

As in most similar Stark broadening studies the self-absorption test is carried out for all reported Si IV spectral lines. Stark broadened halfwidths are given in the table of Numerical results for Si IV. In the same table are reported ratios of experimental results and corresponding SC data evaluated in Ref. 3 (D) and SC results calculated in this work (TW).

CR (1984, 02, 09).

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²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

³A. R. Striganov and N. S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms*, Plenum, New York (1968).

⁴M. S. Dimitrijević, S. Sahal-Brechot, V. Bommier, *Astron. Astrophys. Suppl. Ser.* **89**, 591 (1991).

Finding list

Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.
2120.18	3	3149.56	2	3773.15	4		
2127.47	3	3165.71	2	4088.85	1		
2517.51	5	3762.44	4	4116.10	1		

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Linear low-pressure pulsed arc Discharge is generated in a narrow Pyrex tube 5 mm diameter and 10 cm long partially filled with gas mixture of 90% He + 7% N ₂ + 3% O ₂ to the initial pressure of 665 Pa. Gas pressure is sustained with continuous flow of gas mixture through the discharge tube Silicon is introduced in discharge by sputtering of the glass	Stark width of the He II P _α 4686 Å spectral line	Intensity ratio between Si III (3086.2 Å, 3093.4 Å and 3096.8 Å) and Si IV (3149.6 Å and 3165.7 Å) lines and in addition using the ratio between O II 3973.3 Å and O III 3961.6 Å spectral lines	Plasma observed end-on

Key data on experiments

Numerical results for Si IV

No .	Trans. array	Mult.	Wave. (Å)	Temp . (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m /w _D	w _m / w _{TW}	Acc.	Ref.
1	4 <i>s</i> - 4 <i>p</i>	² S - ² P ^o	4088.85	1900	1	0.296	0.58	0.54	B ⁺	1
			4116.10	0	1	0.265	0.52	0.54	B ⁺	1
				1900						
2	4 <i>p</i> - 4 <i>d</i>	² P ^o - ² D	3149.56	1900	1	0.287	0.75	0.58	B ⁺	1
			3165.71	0	1	0.296	0.76	0.56	B ⁺	1
				1900						
3	4 <i>p</i> - 5 <i>s</i>	² P ^o - ² S	2120.18	1880	1	0.195	0.93	0.66	B	1
			2127.47	0	1	0.222	1.05	0.75	B	1
				1880						
4	4 <i>d</i> - 5 <i>p</i>	² D - ² P ^o		1880	1	0.665	0.84	0.67	B	1
				0	1	0.562	0.69	0.56	B	1
			3762.44	1880						
5	4 <i>f</i> - 5 <i>g</i> [*]	² F ^o - ² G	3773.15	0						
			2517.51	1900	1	0.351		0.63	B	1
				0						
The average ratio values							0.76	0.61		

*The star denotes transition in M5 taken from Striganov and Sventickii²

Sodium

Na I

Ground state: $1s^2 2s^2 2p^6 3s^2 S_{1/2}$

Ionization energy: $5.13907696 \text{ eV} = 41\,449.451 \text{ cm}^{-1}$

The experimental Stark broadening parameters of Na I lines are reported in two publications.^{1,2} The details about experimental procedure and plasma conditions one can find in reports for Ba I and Ba II. The Refs. 1 and 2, except results about Stark parameters for barium give also results for Na I, obtained under same plasma conditions. Therefore, Key data on experiments are identical as appear in reports of Ba I and Ba II. The electron temperature in Ref._2, reported in the table of Numerical results for Na I, are derived from graphical presentation of plasma diagnostic data.

Experimental results for Na I lines, in the table Numerical results, are compared with corresponding SC calculations of halfwidths and shifts evaluated from data in Ref. 3 (G), results from Ref. 4 (DSB) and data calculated in this work (TW).

CR (1976, 84, 02, 09).

References

- ¹J. Hermann, C. Gerhard, E. Axente, C. Dutouquet, *Spectrochim. Acta B* **100**, 189 (2014).
- ²C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet, M. Sentis, W. Viöl, *Spectrochim. Acta B* **101**, 32 (2014).
- ³H. R.Griem, *Spectral Line Broadening by Plasmas*, Academic Press, New York (1974).
- ⁴M. S. Dimitrijević, S. Sahal-Bréchet, J. Quant. Spectrosc. Radiat. Transfer **34**, 149 (1985).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: barite crown glass positioned in chamber filled with argon at 5×10^4 Pa or air at atmospheric pressure	Stark broadening of Si I 3905.5 Å spectral line	Boltzmann plot of Ba I and B II spectral lines and the ratio of Si I and Si II lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam There is no clear explanation about electron density measurement
2	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone

Numerical results for Na I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_G	w_m/w_{DSB}	w_m/w_{TW}	d_m (Å)	d_m/d_G	d_m/d_{DSB}	d_m/d_{TW}	Acc.	Ref.
1	3s - 3p	$^2S -$ $^2P^o$	5889.95	9700	1					0.06	0.46	0.34	0.14		1
				11200	1	0.40	1.18	1.55	1.00	0.15	1.15	0.85	0.35	C ⁺	2
			5895.92	9700	1					0.06	0.46	0.34	0.12	C ⁺ , C ⁺	1
				11200	1	0.40	1.18	1.55	1.00	0.15	1.15	0.85	0.30	C ⁺	2

Strontium

Sr II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^2 S_{1/2}$

Ionization energy: $11.0302765 \text{ eV} = 88\,965.18 \text{ cm}^{-1}$

Two experiments^{1,2} with laser induced plasma as a light source are set up to measure Stark broadening halfwidths and shifts of Sr II spectral line. In both experiments plasma is observed end-on under small angle (15°) in respect to incident laser beam used to induce plasma. According to the authors² this method of plasma observation does not require Abel or some other inversion. Furthermore, it should be pointed out that before determination of Stark broadening parameters in both experiments, the self-absorption test is performed, and Stark parameter of optically thin line is reported in the table of Numerical results for Sr II. The reported electron temperatures, in the table of Numerical results for both experiments, are derived from graphical presentation of plasma diagnostic data (Ref. 1, Fig 7 and Ref. 2, Fig 6).

For comparison experimental and SC results, the calculation is performed in this work (TW) only.

Comment: although measurement of Stark halfwidth in both experiments^{1, 2} are performed under almost identical plasma conditions (electron temperatures differ slightly), see table of Numerical results for Sr II, the reported halfwidths differ considerably indicating an experimental error in halfwidth or plasma parameters measurement.

CR (1976, 84).

References

- ¹C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet, M. Sentis, W. Viöl, Spectrochim. Acta B **101**, 32 (2014).
- ²M. Burger, J. Hermann, Spectrochim. Acta B **122**, 118 (2016).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in the vacuum chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and Si II 3856.0 Å, 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone
2	Nd:YAG laser at 266 nm Single pulse 40 mJ, 4 ns Target: pellet sample of hydrate calcium sulfate powder positioned in the vacuum chamber filled with argon at 5×10^4 Pa	Hydrogen Balmer H_α Stark halfwidth	Boltzmann plot of Ca I and Ca II spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Stark parameters are obtained when agreement between measured and computed spectra occurs

Numerical results for Sr II

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	d_m (Å)	w_m/w_{TW}	d_m/d_{TW}	Acc.	Ref.
1	$5s - 5p$	$^2S - ^2P^o$	4077.71	11200	1	0.16		0.51		B	1

11000	1	0.41	-	1.29	0.30	C ⁺ ,	2
			0.034			C	

Tin

Sn I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2 \ ^3P_0$

Ionization energy: $7.343918 \text{ eV} = 59\,232.69 \text{ cm}^{-1}$

In Ref. 1 a number of Sn I Stark halfwidth results are reported. The plasma is generated in argon under pressure of 6 torr. Neutral tin spectral lines are emitted from plasma obtained by focusing laser beam on plane targets made of Sn or Sn-Pb alloy. Measurements were taken by scanning the plasma in two perpendicular directions. Local profiles were obtained after Abel inversion. The self-absorption test carried out and the instrumental profile is determined.

From the table Numerical results for Sn I it is evident that, within multiplets M1, M6 and M13 differences between measured Stark halfwidths are noticeable. These differences can be explained by irregular disposition of perturbing energy levels in respect to the upper levels² of the observed lines within above mentioned multiplets. The comparison with SC calculations performed in this work (TW) with results of multiplets M1, M2 and M10 show large disagreement. The ratio w_m/w_{TW} for these multiplets varies between 4.51 and 8.97. In some cases, the ratio is not given because the values $\Delta S/S$ go outside of -0.6 and +0.1 frame. From the same reason the average of w_m/w_{TW} was not calculated.

The details of the experimental part of this work one can find in the table Key data of experiments.

CR (1984, 02, 09).

References

¹A. Alonso-Medina, C. Colón, *Astrophys. J.* **672**, 1286 (2008).

²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>.

Finding list

Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.	Wavelength th (Å)	No.
1971.45	6	2380.74	3	2706.51	1	3034.12	1
2140.73	8	2408.15	18	2779.81	12	3141.82	25
2194.50	7	2421.69	17	2785.03	13	3218.68	24
2199.35	5	2429.50	3	2812.56	28	3223.57	11
2231.72	6	2455.25	4	2813.58	13	3262.33	10
2267.19	20	2495.72	16	2839.98	1	3655.78	23
2268.93	4	2523.91	15	2850.62	12	3801.01	9
2286.68	5	2546.55	2	2863.32	1	4524.73	22
2317.23	19	2571.59	13	2913.56	27	5631.68	21
2334.81	4	2594.42	14	3009.13	1		
2354.85	4	2661.24	2	3032.78	26		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser 275 mJ with 7 ns pulse at 1064 nm with repetition rate of 20 Hz in argon at 6 torr Target: Sn and Sn-Pb alloy	Stark width of the three Sn I, five Sn II and two Pb II spectral lines	Boltzmann plots of Sn I, Sn II and Pb II spectral lines	Plasma observed side-on

Numerical results for Sn I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_{TW}	Acc.	Ref. .
1	$5p^2 - 6s$	$^3P - ^3P^o$	2706.51	11000	0.1	0.095	4.94	B	1
			2839.98	11000	0.1	0.108	5.11	B	1
			2863.32	11000	0.1	0.083	6.37	B	1
			3009.13	11000	0.1	0.066	4.55	B	1
			3034.1	11000	0.1	0.083	4.98	B	1
			2						
2	$5p^2 - 6s$	$^3P - ^1P^o$	2546.55	11000	0.1	0.086	7.67	B	1
			2661.24	11000	0.1	0.110	8.97	B	1
3	$5p^2 - 5d$	$^3P - ^3F^o$	2380.74	11000	0.1	0.080	3.38	C ⁺	1
			2429.50	11000	0.1	0.052	1.71	B	1
4	$5p^2 - 5d$	$^3P - ^3D^o$	2268.93	11000	0.1	0.106	1.11	C ⁺	1
			2334.81	11000	0.1	0.109	3.02	C ⁺	1
			2354.85	11000	0.1	0.101	2.49	C ⁺	1
			2455.25	11000	0.1	0.117	2.66	C ⁺	1
5	$5p^2 - 5d$	$^3P - ^1D^o$	2199.35	11000	0.1	0.155	3.32	C ⁺	1
			2286.68	11000	0.1	0.079	1.56	C ⁺	1
6	$5p^2 - 7s$	$^3P - ^3P^o$	1971.45	11000	0.1	0.190		C ⁺	1
			2231.7	11000	0.1	0.086		C ⁺	1
			2						
7	$5p^2 - 5d$	$^3P - ^3P^o$	2194.50	11000	0.1	0.055	0.91	C ⁺	1
8	$5p^2 - 5d$	$^3P - ^1P^o$	2140.73	11000	0.1	0.056	0.79	C ⁺	1
9	$5p^2 - 6s$	$^1D - ^3P^o$	3801.01	11000	0.1	0.046	1.98	B	1
10	$5p^2 - 6s$	$^1D - ^1P^o$	3262.33	11000	0.1	0.082	4.51	B	1
11	$5p^2 - 5p^3$	$^1D - ^5S^o$	3223.57	11000	0.1	0.131		C ⁺	1
12	$5p^2 - 5d$	$^1D - ^3F^o$	2779.81	11000	0.1	0.099	2.49	C ⁺	1
			2850.62	11000	0.1	0.101	2.98	C ⁺	1
13	$5p^2 - 5d$	$^1D - ^3D^o$	2571.59	11000	0.1	0.108	0.88	C ⁺	1
			2785.03	11000	0.1	0.103	2.01	C ⁺	1
			2813.58	11000	0.1	0.128	2.21	C ⁺	1
14	$5p^2 - 5d$	$^1D - ^1D^o$	2594.42	11000	0.1	0.102	1.57	C ⁺	1
15	$5p^2 - 7s$	$^1D - ^3P^o$	2523.91	11000	0.1	0.123	1.64	C ⁺	1
16	$5p^2 - 5d$	$^1D - ^3P^o$	2495.72	11000	0.1	0.039	0.44	C ⁺	1
17	$5p^2 - 5d$	$^1D - ^1F^o$	2421.69	11000	0.1	0.095	1.30	C ⁺	1
18	$5p^2 - 5d$	$^1D - ^1P^o$	2408.15	11000	0.1	0.138	1.54	C ⁺	1
19	$5p^2 - 6d$	$^1D - ^3F^o$	2317.23	11000	0.1	0.181	2.44	C ⁺	1
20	$5p^2 - 7s$	$^1D - ^1P^o$	2267.19	11000	0.1	0.224		C ⁺	1
21	$5p^2 - 6s$	$^1S - ^3P^o$	5631.68	11000	0.1	0.054	1.06	C ⁺	1

Tin

Sn II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2 P^\circ_{1/2}$

Ionization energy: 14.63307 eV = 118 023.7 cm⁻¹

The Stark halfwidth results for Sn II lines are reported in Ref. 1 together with Sn I results measured using same plasma source, conditions, and experimental procedure.

The experimental data are compared with SC calculations of this work (TW), see the table of Numerical results for Sn II. Only in multiplets M1 and M2 one can see large discrepancies between experimental and theoretical results. The theory predicts much lower Stark halfwidths, which may be explained by distant positions of perturbing energy levels², from the levels of studied transition. Furthermore, one can notice some disagreement between experimental Stark halfwidths within multiplets M4, M6, M7, M12 and M13. The difference within M4 halfwidths is in agreement with the theoretical calculations, while for the rest of the multiplets this is not the case. The theoretical Stark halfwidths within multiplets M6, M7, M12 and M13 vary only few percents similar to the energy spread of perturbing levels, see Ref. 2.

The experimental details, which are the same as in Sn I case, one can find in the table Key data of experiments.

CR (1984, 90, 02, 09).

References

¹A. Alonso-Medina, C. Colón, *Astrophys. J.* **672**, 1286 (2008).

²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>.

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
1899.90	2	2990.99	6	3575.33	13	5561.91	11
2266.02	1	2994.46	14	3582.35	13	5588.82	8
2368.23	1	3023.92	6	3619.96	9	5596.26	11

2448.91	7	3047.44	6	3620.49	9	6453.54	4
2486.60	7	3283.14	5	3715.15	12	6760.81	10
2486.97	7	3472.33	13	3841.38	12	6844.19	4
2592.30	3	3537.47	9	5332.34	11		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser 275 mJ with 7 ns pulse width at 1064 nm with repetition rate of 20 Hz Vacuum chamber filled with 6 torr of argon Target: Sn and Sn-Pb alloy	Stark width of the three Sn I, five Sn II and two Pb II spectral lines	Boltzmann plots of Sn I, Sn II and Pb II spectral lines	Plasma observed side-on

Numerical results for Sn II

No .	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	Acc.	Ref .
1	$5p - 5p^2$	$^2P^o - ^4P$	2266.02	11000	0.1	0.056	18.25	C ⁺	1
			2368.23	11000	0.1	0.049	14.63	C ⁺	1
2	$5p - 6s$	$^2P^o - ^2S$	1899.90	11000	0.1	0.130	14.06	C ⁺	1
3	$5p^2 - 4f$	$^4P - ^2F^o$	2592.30	11000	0.1	0.130	2.26	C ⁺	1
4	$6s - 6p$	$^2S - ^2P^o$	6453.54	11000	0.1	0.290	0.74	B	1
			6844.19	11000	0.1	0.420	0.62	B	1
5	$5p^2 - 4f$	$^2D - ^2F^o$	3283.14	11000	0.1	0.130	1.41	B	1
6	$5p^2 - 7p$	$^2D - ^2P^o$	2990.99	11000	0.1	0.130	1.24	C ⁺	1
			3023.92	11000	0.1	0.130	1.12	C ⁺	1
			3047.44	11000	0.1	0.270	2.49	B	1
7	$5p^2 - 5f$	$^2D - ^2F^o$	2448.91	11000	0.1	0.220	1.15	B	1
			2486.60	11000	0.1	0.210	1.06	C ⁺	1
			2486.97	11000	0.1	0.150	0.77	B	1
8	$5d - 4f$	$^2D - ^2F^o$	5588.82	11000	0.1	0.360	1.14	B	1
9	$5d - 5f$	$^2D - ^2F^o$	3537.47	11000	0.1	0.440	1.06	B	1
			3619.96	11000	0.1	0.390	0.88	B	1
			3620.49	11000	0.1	0.390	0.89	C ⁺	1
10	$6p - 7s$	$^2P^o - ^2S$	6760.81	11000	0.1	0.600	0.75	C ⁺	1
11	$6p - 6d$	$^2P^o - ^2D$	5332.34	11000	0.1	0.550	0.90	B	1
			5561.91	11000	0.1	0.550	1.07	B	1
			5596.26	11000	0.1	0.630	1.19	B	1
12	$6p - 8s$	$^2P^o - ^2S$	3715.15	11000	0.1	0.720	2.04	C ⁺	1
			3841.38	11000	0.1	0.370	1.25	B	1
13	$6p - 7d$	$^2P^o - ^2D$	3472.33	11000	0.1	0.560	1.15	C ⁺	1
			3575.33	11000	0.1	0.560	1.23	C ⁺	1
			3582.35	11000	0.1	0.390	0.83	C ⁺	1
14	$6p - 8d$	$^2P^o - ^2D$	2994.46	11000	0.1	0.680	0.98	B	1
The average ratio value							1.18*		

*The average w_m/w_{TW} is evaluated without the ratios M1 and M2.

Tin

Sn III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2$ 1S_0

Ionization energy: 30.506 eV = 246 047 cm^{-1}

Only one experiment¹ reports experimental Stark halfwidths of several Sn III lines, measured in linear low pressure, pulsed arc. The Sn III ions, in plasma, are generated by evaporation and ionization of cylindrical tin plates located in the homogeneous part of the discharge tube.

Self-absorption test carried out and instrumental profile is measured.

Unfortunately, the comparison with SC calculations of this work (TW) is performed only for the single line from multiplet M2 of the table Numerical results for Sn III. In other cases where $\Delta S/S < -0.7$, comparison with calculated Stark parameters is not reported.

The details of the experimental part of this work are described in the table Key data of experiments.

CR (2009).

Reference

¹S. Djeniže, Spectrochim. Acta B **62**, 403 (2007).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2069.98	1	2631.81	3	2646.07	3	2896.07	2
2618.68	4	2643.53	3	2658.56	3		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Low pressure pulsed arc Working gas 90% He + 7% N ₂ + 3% O ₂ at pressure of 1330 Pa and 133 Pa Tin evaporated from cylindrical plates located in the homogeneous part of the discharge tube	Stark halfwidth of He II P α spectral line	Ratio of intensity between O II 3954.26 Å O II 3973.26 Å and O III 3961.57 Å spectral lines	Plasma observed axially end-on

Numerical results for Sn III

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	w_m (Å)	w_m/w_{TW}	Acc.	Ref
1	5 <i>p</i> - 5 <i>p</i> ²	¹ P ^o - ¹ D	2069.98	17500	1.07	0.172	1.01	B ⁺	1
2	5 <i>p</i> ² - 6 <i>p</i>	¹ D - ¹ P ^o	2896.07	17500	1.07	0.320		B ⁺	1
3	5 <i>s</i> 5 <i>d</i> -	³ D - ³ F ^o	2631.81	17500	1.07	0.132		B ⁺	1
	4 <i>f</i> 5 <i>s</i>		2643.53	17500	1.07	0.140		B ⁺	1
			2646.07	17500	1.07	0.120		B ⁺	1
			2658.56	17500	1.07	0.145		B ⁺	1
4	5 <i>s</i> 5 <i>d</i> -	³ D - ¹ F ^o	2618.68	17500	1.07	0.124		B ⁺	1
	4 <i>f</i> 5 <i>s</i>								

Tin

Sn IV

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 S_{1/2}$

Ionization energy: 40.74 eV = 328 550 cm⁻¹

In Ref. 1 are reported the experimental Stark halfwidths of Sn IV together with Sn III results. For the experimental details see Sn III report and present table of Key data on experiments.

The comparison of experimental Stark halfwidth with SC calculated data in this work (TW) is shown in the table of Numerical results for Sn IV. Since in NIST Database², the list of Sn IV lines and their wavelengths is not available the corresponding transitions in the table of Numerical results for Sn IV are given as appeared in Ref. 1. The exception is line 2436.88 Å, which is located in M5 with the transition deduced from the list of energy levels in Ref. 2.

For the M4 result, in the table of Numerical results for Sn IV, the comparison with the theory is not given because of the incomplete set of perturbing levels ($\Delta S/S < -0.7$).

References

¹S. Djeniže, Spectrochim. Acta B **62**, 403 (2007).

²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>.

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2083.00	4	2229.13	2	2849.00	3		
2220.88	2	2436.88	5	2887.66	1		
2226.13	2	2706.00	3	3072.00	1		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Low pressure pulsed arc Discharge gas 90% He + 7% N ₂ + 3% O ₂ at pressure of 1330 Pa and 133 Pa Tin evaporated from cylindrical plates located in the homogeneous part of the discharge tube	Stark halfwidth of He II P α spectral line	Ratio of intensity between O II 3954.26 Å O II 3973.26 Å and O III 3973.26 Å spectral lines	Plasma observed axially end-on

Numerical results for Sn IV

No .	Trans. array	Mult.	Wave. (Å)	Temp . (K)	Electron density (10 ¹⁷ cm ⁻³)	w _m (Å)	w _m / w _{TW}	Acc.	Ref .
1	5 <i>d</i> – 6 <i>p</i>	² D – ² P ^o	2887.66	1750	1.07	0.240	0.83	B ⁺	1
			3072.00	0	1.07	0.265	0.82	B ⁺	1
				1750					
2	5 <i>d</i> – 4 <i>f</i>	² D – ² F ^o	2220.88	1750	1.07	0.145	1.04	B ⁺	1
			2226.13	0	1.07	0.200	1.72	B ⁺	1
			2229.13	1750	1.07	0.148	1.07	B ⁺	1
				0					
				1750					
3	6 <i>p</i> – 6 <i>d</i>	² P ^o – ² D	2706.00	1750	1.07	0.220	0.78	B ⁺	1
			2849.00	0	1.07	0.228	0.72	B ⁺	1
				1750					
4	4 <i>f</i> – 5 <i>g</i>	² F ^o – ² G	2083.00	1750	1.07	0.224		B ⁺	1
				0					
5	5 <i>s</i> ² – 4 <i>f</i>	² D – ² F ^o	2436.88	1750	1.07	0.160	1.14	B ⁺	1
				0					
The average ratio value							1.02		

Titanium

Ti II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^1 {}^4F_{3/2}$

Ionization energy: $13.5755 \text{ eV} = 109\,494 \text{ cm}^{-1}$

Two laser-induced experiments^{1,2} are carried out to determine Stark broadening parameters of Ti II spectral lines. The experimental data for Stark halfwidths and shifts are compared with SC calculations performed in this work (TW). The comparison between experimental results and SC calculations is quite reasonable for the Stark halfwidths (the average ratio value is 0.70). Only for M24 there is no comparison experimental and theoretical Stark parameters because of $\Delta S/S$ is larger of -0.6. The experimental and SC Stark shifts show in a number of cases, opposite wavelength shift and therefore, the average ratio is not given in the table of Numerical results for Ti II. It should be noticed in addition that shifts of Ti II lines are very small in most cases.

The electron temperature of 11200 K used with Ref. 1 is derived from graphical presentation of plasma diagnostic data, see Fig. 7 in Ref. 1. The comment about temperature for Ref. 2 is given under the table of Numerical results.

References

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- ²J. Manrique, J. A. Aguilera, C. Aragón, *Month. Not. Roy. Astron. Soc.* **462**, 1501 (2016).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
2517.43	9	3046.69	21	3315.32	27	3721.64	10
2525.60	9	3075.22	5	3318.02	7	3748.00	43
2529.75	9	3078.64	5	3322.93	7	3759.29	10
2531.25	9	3088.03	5	3332.11	27	3761.32	10
2534.62	9	3097.18	29	3341.87	11	3776.05	30
2535.87	9	3103.80	38	3361.21	1	3900.54	18
2635.45	47	3106.23	29	3366.18	25	3913.46	18
2638.56	47	3117.67	29	3372.79	1	4163.64	42
2746.54	48	3119.80	29	3383.76	1	4171.90	42
2761.29	16	3148.04	4	3402.42	25	4294.09	14
2817.81	45	3152.25	8	3444.31	6	4307.87	20
2832.18	12	3154.19	8	3456.38	40	4386.85	41
2834.01	44	3168.52	8	3461.50	6	4395.03	13
2836.48	44	3190.87	15	3465.55	40	4399.77	23
2839.64	45	3197.52	3	3483.63	49	4443.80	13
2841.94	12	3218.27	34	3504.89	36	4501.27	17
2851.10	26	3224.24	34	3520.25	39	4549.62	33
2877.44	19	3234.52	2	3535.41	39	4563.76	22
2884.10	19	3241.98	2	3624.83	24	4571.97	33
2935.98	46	3254.25	2	3641.33	24		
2945.29	46	3282.33	28	3662.23	32		
3017.18	35	3287.65	37	3706.22	31		

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass positioned in chamber filled with argon at 5×10^4 Pa	Halfwidth of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856.0 Å , 3862.6 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the plasma generating laser beam Plasma divided in zones and calculated plasma parameters for each zone
2	Nd:YAG laser at 1064 nm, 4.5 ns, 60 mJ, 20 Hz Target: fused glass samples from pure titanium oxide at atmospheric pressure	H $_{\alpha}$ Stark halfwidth	Boltzmann plot of seven Ti II spectral lines	Plasma observed side-on Abel inversion not performed

Key data on experiments

Numerical results for Ti II

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm $^{-3}$)	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref
1	$(^3F)4s - (^3F)4p$	a $^4F - z$ $^4G^o$	3361.21	13700	1	0.070	0.50	-	0.10	B, B	2
			3372.79	13700	1	2	0.51	0.004	0.15	B, B	2
			3383.76	13700	1	0.072	0.48	3	0.14	B, B	2
						4		-			
								0.006			

						0.068		5			
						8		-			
								0.006			
								2			
2	$(^3F)4s - (^3F)4p$	a $^4F - z$ $^4F^o$	3234.52	13700	1	0.085	0.65	-	0.15	B, B	2
			3241.98	13700	1	2	0.59	0.006	0.25	B, B	2
			3254.25	13700	1	0.077	0.62	1	-/+	B, B	2
						4		-			
						0.078		0.009			
						3		7			
								-			
								0.010			
								1			
3	$(^3F)4s - (^3F)4p$	a $^4F - z$ $^2F^o$	3197.52	13700	1	0.083	0.54			B	2
						1					
4	$(^3F)4s - (^3F)4p$	a $^4F - z$ $^2D^o$	3148.04	13700	1	0.074	0.43	-	0.29	B, B	2
						3		0.012			
								8			
5	$(^3F)4s - (^3F)4p$	a $^4F - z$ $^4D^o$	3075.22	13700	1	0.072	0.61	-	-/+	B, B	2
			3078.64	13700	1	7	0.59	0.007	0.27	B, B	2
			3088.03	13700	1	0.071	0.58	0	0.16	B, B	2
						0		-			
						0.069		0.006			
						9		5			
								-			
								0.005			
								6			
6	$3d^3 - (^3F)4p$	b $^4F - z$ $^4G^o$	3444.31	13700	1	0.107	0.81	0.03	0.66	B, B	2
			3461.50	13700	1	3	0.79	55	0.67	B, B	2
						0.106		0.03			
						1		56			

7	$3d^3 - ({}^3F)4p$	$b {}^4F - z {}^4F^o$	3318.02	13700	1	0.092	0.75	0.02	0.57	B, B	2
			3322.93	13700	1	1	0.80	78	0.69	B, B	2
						0.101		0.03			
8	$3d^3 - ({}^3F)4p$	$b {}^4F - z {}^4D^o$	3152.25	13700	1	0.090	0.79	0.02	0.60	B, B	2
			3154.19	13700	1	3	0.71	77	0.65	B, B	2
			3168.52	13700	1	0.081	0.74	0.02	0.66	B, B	2
						3		99			
						0.087		0.02			
9	$3d^3 - ({}^3P)4p$	$b {}^4F - y {}^4D^o$	2517.43	13700	1	0.055	0.76	0.02	0.72	B, B	2
			2525.60	13700	1	0	0.81	03	0.79	B, B	2
			2529.75	13700	1	0.059	0.76	0.02	0.74	B, B	2
			2531.25	13700	1	6	0.76	17	0.76	B, B	2
			2534.62	13700	1	0.055	0.76	0.02	0.76	B, B	2
			2535.87	13700	1	6	0.77	05	0.76	B, B	2
						0.056		0.02			
						1		09			
						0.055		0.02			
						9		08			
10	$({}^3F)4s - ({}^3F)4p$	$a {}^2F - z {}^2F^o$	3721.64	13700	1	0.115	0.59	-	-/+	B, B	2
			3759.29	13700	1	4	0.56	0.013	0.30	B, B	2
			3761.32	11200	1	0.116	0.68	6		C ⁺	1
				13700	1	8	0.58	-	0.26	B, B	2
						0.150		0.018			
						0		8			
						0.122					
						1		-			
								0.017			

11	$(^3\text{F})4s - (^3\text{F})4p$	$a \ ^2\text{F} - z$ $\ ^2\text{G}^\circ$	3341.87	13700	1	0.088	0.58	1 - 0.005	0.11	B, B	2
12	$(^3\text{F})4s - (^1\text{D})4p$	$a \ ^2\text{F} - y \ ^2\text{F}^\circ$	2832.18	13700	1	0.059	0.54	5 - 0.004	0.10	B, B	2
			2841.94	13700	1	1 0.060 0	0.55	6 - 0.005	0.11	B, B	2
13	$(^1\text{D})4s - (^3\text{F})4p$	$a \ ^2\text{D} - z$ $\ ^2\text{F}^\circ$	4395.03	13700	1	0.170	0.57	4 - 0.010	0.10	B, B	2
			4443.80	13700	1	7 0.162 8	0.53	4 - 0.008	0.08	B, B	2
14	$(^1\text{D})4s - (^3\text{F})4p$	$a \ ^2\text{D} - z$ $\ ^2\text{D}^\circ$	4294.09	13700	1	0.124	0.36	9 - 0.008	0.10	B, B	2
15	$(^1\text{D})4s - (^1\text{D})4p$	$a \ ^2\text{D} - y$ $\ ^2\text{F}^\circ$	3190.87	13700	1	0.082	0.67	6		B	2
16	$(^1\text{D})4s - (^3\text{P})4p$	$a \ ^2\text{D} - x$ $\ ^2\text{D}^\circ$	2761.29	13700	1	0.062	0.60			B	2
17	$3d^3 - (^3\text{F})4p$	$a \ ^2\text{G} - z$ $\ ^2\text{F}^\circ$	4501.27	13700	1	0.186	0.68	0.03 58	0.44	B, B	2
18	$3d^3 - (^3\text{F})4p$	$a \ ^2\text{G} - z$ $\ ^2\text{G}^\circ$	3900.54	13700	1	0.146	0.77	0.03 62	0.58	B, B	2
			3913.46	13700	1	9 0.155 0	0.82	70 0.03	0.58	B, B	2
19	$3d^3 - (^1\text{G})4p$	$a \ ^2\text{G} - y$ $\ ^2\text{G}^\circ$	2877.44	13700	1	0.087	0.95	0.02 02	0.65	B, B	2
			2884.10	13700	1	6	0.86		0.58	B, B	2

						0.079		0.01			
						1		82			
20	$3d^3 - ({}^3F)4p$	$a {}^4P - z {}^4D^o$	4307.87	13700	1	0.148	0.69	0.04	0.57	B, B	2
						5		81			
21	$3d^3 - ({}^3P)4p$	$a {}^4P - z {}^4P^o$	3046.69	13700	1	0.107	1.03	0.02	0.87	B, B	2
						5		89			
22	$3d^3 - ({}^3F)4p$	$a {}^2P - z {}^2D^o$	4563.76	13700	1	0.164	0.47	0.01	0.17	B, B	2
						8		69			
23	$3d^3 - ({}^3F)4p$	$a {}^2P - z {}^4D^o$	4399.77	13700	1	0.149	0.66	0.02	0.33	B, B	2
						3		91			
24	$3d^3 - ({}^3P)4p$	$a {}^2P - z {}^2S^o$	3624.83	13700	1	0.106				B	2
			3641.33	13700	1	3		0.00		B, B	2
						0.108		36			
						0					
25	$3d^3 - ({}^1D)4p$	$a {}^2P - z {}^2P^o$	3366.18	13700	1	0.091	0.62			B	2
			3402.42	13700	1	5	0.63	0.01	0.25	B, B	2
						0.094		59			
						2					
26	$3d^3 - ({}^3P)4p$	$a {}^2P - x {}^2D^o$	2851.10	13700	1	0.075	0.72	0.01	0.36	B, B	2
						0		33			
27	$({}^3P)4s - ({}^3P)4p$	$b {}^4P - z {}^4S^o$	3315.32	13700	1	0.087	0.65			B	2
			3332.11	13700	1	4	0.58	-	0.13	B, B	2
						0.078		0.008			
						9		2			
28	$({}^3P)4s - ({}^3P)4p$	$b {}^4P - y {}^4D^o$	3282.33	13700	1	0.071	0.59				2
						5					
29	$({}^3P)4s - ({}^3P)4p$	$b {}^4P - z {}^4P^o$	3097.18	13700	1	0.070	0.62	0.00	+/-	B, B	2
			3106.23	13700	1	0	0.58	05	+/-	B, B	2
			3117.67	13700	1	0.066	0.64	0.00		B	2
			3119.80	13700	1	5	0.62	07		B	2
						0.072					

						8						
						0.070						
						7						
30	$3d^3 - ({}^1D)4p$	b ${}^2D - z$	3776.05	13700	1	0.131	0.71	0.02	0.32	B, B	2	
		${}^2P^o$				7		54				
31	$3d^3 - ({}^1D)4p$	b ${}^2D - y$	3706.22	13700	1	0.128	0.71	0.02	0.29	B, B	2	
		${}^2D^o$				7		08				
32	$3d^3 - ({}^1D)4p$	b ${}^2D - y$	3662.23	13700	1	0.135	0.76	0.02	0.33	B, B	2	
		${}^2F^o$				8		21				
33	$3d^3 - ({}^3F)4p$	a ${}^2H - z$	4549.62	13700	1	0.196	0.58	0.04	+/-	B, B	2	
		${}^2G^o$	4571.97	13700	1	5	0.72	85	0.55	B, B	2	
						0.186		0.04				
						7		88				
34	$3d^3 - ({}^1G)4p$	a ${}^2H - y$	3218.27	13700	1	0.091	0.77	0.02	0.58	B, B	2	
		${}^2G^o$	3224.24	13700	1	8	0.63	06	+/-	B, B	2	
						0.091		0.02				
						5		39				
35	$3d^3 - ({}^1G)4p$	a ${}^2H - z$	3017.18	13700	1	0.090	0.97	0.02	+/-	B, B	2	
		${}^2H^o$				2		84				
36	$({}^1G)4s - ({}^1G)4p$	b ${}^2G - y$	3504.89	13700	1	0.107	0.71	-	0.17	B, B	2	
		${}^2G^o$				1		0.008				
								4				
37	$({}^1G)4s - ({}^1G)4p$	b ${}^2G - z$	3287.65	13700	1	0.080	0.61			B	2	
		${}^2H^o$				0						
38	$({}^1G)4s - ({}^1G)4p$	b ${}^2G - x$	3103.80	13700	1	0.073	0.61	0.00	+/-	B, B	2	
		${}^2F^o$				4		03				
39	$({}^3P)4s - ({}^3P)4p$	b ${}^2P - x$	3520.25	13700	1	0.114	0.71	0.00	+/-	B, B	2	
		${}^2D^o$	3535.41	13700	1	8	0.76	79	+/-	B, B	2	
						0.123		0.00				
						0		77				
40	$({}^3P)4s - ({}^3P)4p$	b ${}^2P - y$ ${}^2P^o$	3456.38	13700	1	0.104	0.66	0.00	+/-	B, B	2	

			3465.55	13700	1	9 0.104 8	0.69	79 0.00 50	+/-	B, B	2
41	$3d^3 - ({}^1G)4p$	$b {}^2F - y {}^2G^o$	4386.85	13700	1	0.169 4	0.74	0.03 92	0.58	B, B	2
42	$3d^3 - ({}^3P)4p$	$b {}^2F - x {}^2D^o$	4163.64	13700	1	0.175 3	0.66	0.04 17	+/-	B, B	2
			4171.90	13700	1	0.172 2	0.65	0.04 26	+/-	B, B	2
43	$3d^3 - ({}^1G)4p$	$b {}^2F - x {}^2F^o$	3748.00	13700	1	0.131 3	0.75	0.03 52	0.65	B, B	2
44	$({}^3F)4p - ({}^3F)4d$	$z {}^4G^o - e {}^4G$	2834.01	13700	1	0.182 8	0.78	0.09 70	0.83	B, B	2
			2836.48	13700	1	0.164 1	0.71	0.09 90		B	2
45	$({}^3F)4p - ({}^3F)4d$	$z {}^4G^o - e {}^4H$	2817.81	13700	1	0.197 8	0.83	0.09 90	0.82	B, B	2
			2839.64	13700	1	0.203 3	0.83	0.11 24	0.89	B, B	2
46	$({}^3F)4p - ({}^3F)4d$	$z {}^4F^o - e {}^4G$	2935.98	13700	1	0.210 4	0.85	0.11 38	0.93	B, B	2
			2945.29	13700	1	0.246 2	0.98	0.11 00	0.88	B, B	2
47	$({}^3F)4p - ({}^3F)4d$	$z {}^4F^o - f {}^4F$	2635.45	13700	1	0.303 5	0.96	0.13 31	0.86	B, B	2
			2638.56	13700	1	0.298 7	0.94	0.14 55	0.94	B, B	2
48	$({}^3F)4p - ({}^3F)4d$	$z {}^2F^o - e {}^2G$	2746.54	13700	1	0.237 6	0.90	0.12 14	0.94	B, B	2
49	$({}^3F)4p - ({}^3F)5s$	$z {}^2G^o - e {}^2F$	3483.63	13700	1	0.482 7	1.06	0.19 73	0.80	B, B	2

The average ratio values

0.70

In the Ref. 2 the authors report that Stark halfwidth data in temperature interval 11970 – 15520 K.
In the above table of Numerical results the average temperature value of 13700 K is used.

Tungsten

W I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^4 5d^4 6s^2 \ ^5D_0$

Ionization energy: 7.86403 eV = 63 427.7 cm⁻¹

Pure tungsten and tungsten carbide are used as targets to induce plasma with Q-switched Nd:YAG laser which is used in this study of W I lines. For plasma diagnostics and other details of experiment see the table Key data on experiment.

In this case there are no comparisons experimental and semiclassical calculations because parameter $\Delta S/S$ exceeds limit of - 0.6.

Reference

¹D. Nishijima, R. P. Doerner, J. Phys. D: Appl. Phys. **48**, 325201 (2015).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Q-switched Nd:YAG laser, 1064 nm, 5 ns, 230 mJ or 340 mJ Target of pure tungsten, W, or tungsten carbide, WC, are located in vacuum chamber The experiment carried out in air At the pressures 0.5 Torr and 5 Torr	Stark broadening of CII 4267 Å spectral line	Boltzmann plot of 14 W I spectral lines	Plasma observed end-on within small angle in respect to the incident laser beam The possibility of self-absorption of W I lines is commented

Numerical results for W I

No.	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	Acc.	Ref.
1	(6S)6s - (6D)6p	7S - 7D°	4302.11	9600	0.19	0.0537	C	1
				11500	0.41	0.1570	C	1
2	(6S)6s - (6S)6p	7S - 7P°	4294.61	8500	0.12	0.0727	C	1
				11600	0.41	0.2260	C	1
3	(6S)6s - (6S)6p	7S - °	4269.38	8500	0.12	0.0940	C	1
				11500	0.41	0.2480	C	1

Uranium

U I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^{10} 6s^2 6p^6 5f^3 6d^7 s^2 \ ^5L^{\circ}_6$
 Ionization energy: 6.19405 eV = 49 958.4 cm⁻¹

Nd:YAG laser is used to induce uranium plasma, which is extensively characterized by means of the optical emission spectroscopy and used for the measurement of Stark halfwidth of U I 4990.1 Å line. All details of the experimental setup and plasma diagnostic procedures are described in the table Key data on experiments. In particular it is important to stress that the U I line self-absorption is checked while all line plasma observations are carried out side-on without the application of Abel inversion procedure.

It should be underlined that spectral line data for studied U I line are not available in NIST Database² and Striganov and Sventickii data selection³ and therefore atomic data for this line is missing in the Numerical results for U I line. From the same reason the comparison with theoretical prediction is missing.

References

¹M. Burger, P. J. Skrodzki, I. Jovanović, M. C. Phillips, S. S. Harilal, Phys. Plasmas **26**, 093103 (2019).

²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

³A. R. Striganov and N. S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms*, Plenum, New York (1968).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm, 6 ns, 75 mJ Uranium metal target in chamber filled with pure nitrogen under pressure of 0.67 Pa	Stark broadening of impurity O I 7771.9 Å spectral line	Boltzmann plot of atomic uranium lines	Plasma observed side-on The Abel inversion is not performed

Numerical results for U I

No	Trans.	Mult.	Wave.	Temp.	Electron density	w_m	Acc.	Ref.
.	array		(Å)	(K)	(10^{17} cm^{-3})	(Å)		
1			4990.10	6000	0.1	0.06	D	1

Uranium

U II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 4f^{14} 5d^{10} 6s^2 6p^6 5f^7 s^2$ $^4I^{\circ 9}_{1/2}$

Ionization energy: 11.6 eV = 93 500 cm⁻¹

The Stark halfwidth parameter of U II 5008.21 Å spectral line was measured under same plasma conditions as for U I 4990.1 Å line.¹ The experimental data are given in the table Key data on experiment.

The same comment as for U I line applies here. Spectral line transition data for studied U II line are not available in NIST Database² and in Striganov and Sventickii data selection³ and therefore, atomic data for this line, as well as the comparison with theoretical data are missing in the table of Numerical results for U II line.

References

¹M. Burger, P. J. Skrodzki, I. Jovanović, M. C. Phillips, S. S. Harilal, Phys. Plasmas **26**, 093103 (2019).

²NIST Atomic Spectra Database, <https://www.nist.gov/pml/atomic-spectra-database>

³A. R. Striganov and N. S. Sventitskii, *Tables of Spectral Lines of Neutral and Ionized Atoms*, Plenum, New York (1968).

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm, 6 ns, 75 mJ Uranium metal target in chamber filled with pure nitrogen under pressure of 0.67 Pa	Stark broadening of impurity O I 7771.9 Å spectral line	Boltzmann plot of atomic uranium lines	Plasma observed side-on The Abel inversion is not performed

Numerical results for U II

No	Trans.	Mult.	Wave.	Temp.	Electron density	w_m	Acc.	Ref.
.	array		(Å)	(K)	(10^{17} cm^{-3})	(Å)		
1			5008.20	6000	0.1	0.12	D	1

Vanadium

V II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4 \ ^5D_0$

Ionization energy: $14.634 \text{ eV} = 118\,030 \text{ cm}^{-1}$

In the Manrique et al paper¹ the Stark parameters of 147 spectral lines, belonging to 75 multiplets, are reported. As plasma source Q-switched Nd: YAG laser was used. To avoid large influence of self-absorption effect the appropriate atomic concentration of vanadium in V_2O_5 target is selected. Within this publication¹ there is no information about the direction of spectroscopic plasma observation (side-on or end-on) and therefore, it is not clear whether Abel inversion procedure is applied.

The experimental Stark widths and shifts are compared with SC data evaluated in this work (TW). The comparison for M19, M22, M26, M33, M34, M45, M52, M72 and M73 multiplets are not reported in the table of Numerical results for V II because $\Delta S/S$ is outside of -0.6 limit. In the other cases, w_m/w_{TW} ratio show reasonable agreement between experimental and theoretical Stark halfwidth values. The exception is multiplet M74 where experimental halfwidths are larger between 1.5 to 2 times from theoretical results. In the same time one can notice relatively large disagreement between measured halfwidths for the lines in multiplet M74.

The measured shifts are very small and the average value of d_m/d_{TW} show large variation and disagreement with theoretical shift values. Furthermore, many shifts are mutually oriented in opposite direction and from that reason the average value of d_m/d_{TW} is not reported in the table of Numerical results for V II.

Reference

¹J. Manrique, D. M. Díaz Pace, C. Aragón, J. A. Aguilera, Month. Not. Roy. Astron. Soc. **498**, 2068 (2020).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
2023.57	61	2845.24	60	3042.26	38	3337.82	69
2131.84	4	2847.57	59	3063.24	58	3485.92	11
2342.14	22	2854.34	59	3067.10	31	3493.16	11
2352.18	22	2869.13	59	3083.21	55	3497.03	63
2380.91	15	2880.03	8	3100.93	37	3504.44	11
2453.35	34	2882.50	8	3102.30	5	3517.30	11
2465.27	37	2888.24	32	3110.71	5	3520.02	9
2514.64	14	2889.62	8	3113.56	68	3530.77	10
2549.28	19	2896.21	6	3118.38	5	3545.20	9
2577.68	26	2903.08	6	3125.29	5	3556.80	9
2584.95	42	2906.46	6	3126.22	5	3560.59	10
2630.66	33	2911.06	7	3130.27	5	3566.18	10
2642.21	33	2930.81	7	3133.33	5	3589.76	9
2644.33	74	2934.40	7	3136.52	57	3592.02	10
2645.84	33	2944.57	7	3139.75	57	3593.33	10
2649.33	74	2949.18	66	3142.48	44	3618.93	65
2655.65	74	2952.07	7	3151.32	62	3621.21	48
2663.21	74	2955.58	71	3155.40	43	3661.37	70
2672.00	3	2957.52	6	3164.84	13	3669.42	56
2677.80	3	2968.38	27	3174.53	72	3715.46	20
2679.32	3	2972.26	51	3187.71	13	3727.34	23
2687.95	3	2973.97	73	3188.51	13	3732.75	20
2700.93	2	2981.20	51	3190.68	13	3745.80	20
2702.18	1	2983.56	27	3208.35	13	3770.97	23
2706.16	2	2985.18	73	3214.75	13	3787.24	53
2715.66	2	2988.03	28	3217.11	36	3847.33	64
2728.64	2	2996.00	28	3237.87	36	3878.71	30
2765.66	21	3001.20	28	3250.77	67	3899.13	30
2768.56	21	3005.81	50	3251.86	54	3903.25	18
2775.76	52	3012.02	40	3254.77	36	3914.32	30
2781.40	75	3013.10	27	3257.89	54	3951.96	16
2797.01	41	3014.82	28	3265.89	47	3973.63	17
2802.79	25	3022.58	27	3267.70	12	4005.70	29

2803.46	25	3023.88	39	3271.12	12	4023.38	29
2817.50	45	3024.98	49	3276.13	12	4035.62	29
2819.43	45	3028.05	49	3282.53	46	4183.43	35
2836.52	24	3041.42	38	3298.74	12		

Key data on experiments

Ref.	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Q-switched Nd: YAG laser at 1064 nm with 4.5 ns pulse time length and 60 mJ per pulse. Target: pure V_2O_5 in powder form prepared as fused glass discs Plasma generated in air at atmospheric pressure	Stark widths of C II 3933.66 and 3968.47 Å and Balmer $H\alpha$ line.	Boltzmann plot of 22 V II spectral lines	

Numerical results for V II

No.	Trans. array	Mult.	Wave. (Å)	Temp. * (K)	Electron	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
					density (10^{17} cm^{-3})						
1	$3d^4 - 4p$	a $^5D - z$ $^3D^o$	2702.18	12950	1	0.068	0.73	0.018 0	0.80	B, B	1
2	$3d^4 - 4p$	a $^5D - z$ $^5F^o$	2700.93	12950	1	0.064	0.80	0.023	0.74	B, B	1
			2706.16	12950	1	0.062	0.78	3	0.67	B, B	1
			2715.66	12950	1	0.065	0.81	0.021	0.65	B, B	1
			2728.64	12950	1	0.066	0.82	1	0.65	B, B	1
3	$3d^4 - 4p$	a $^5D - z$ $^5D^o$						0.020 4			
								0.020 9			
			2672.00	12950	1	0.064	0.83	0.019	0.63	B, B	1
			2677.80	12950	1	0.064	0.82	3	0.63	B, B	1
4	$3d^4 - 4p$	a $^5D - y$ $^5D^o$	2679.32	12950	1	0.065	0.84	0.019	0.58	B, B	1
			2687.95	12950	1	0.064	0.81	0	0.72	B, B	1
								0.018 0			
								0.020 8			
5	$4s - 4p$	a $^5F - z$ $^5G^o$	2131.84	12950	1	0.038	0.81			B, B	1
5	$4s - 4p$	a $^5F - z$ $^5G^o$	3102.30	12950	1	0.061	0.54	-	0.06	B, B	1
			3110.71	12950	1	0.060	0.53	0.0019	0.08	B, B	1
			3118.38	12950	1	0.064	0.56	-	0.09	B, B	1
			3125.29	12950	1	0.070	0.60	0.0026	0.11	B, B	1
			3126.22	12950	1	0.060	0.56	-	-/+	B, B	1
			3130.27	12950	1	0.060	0.56	0.0032	-/+	B, B	1
			3133.33	12950	1	0.063	0.58	-	-/+	B, B	1
								0.0042 - 0.0026 - 0.0033 - 0.0025			
6	$4s - 4p$	a $^5F - z$ $^3D^o$									
			2896.21	12950	1	0.061	0.50	-	0.11	B, B	1
			2903.08	12950	1	0.062	0.50	0.0054	0.08	B, B	1
			2906.46	12950	1	0.069	0.56	-	0.09	B, B	1
			2957.52	12950	1	0.056	0.42	0.0040	0.10	B, B	1

Ref. 1 reports the results in the electron temperature range 11000 to 14900 K.
In the Table is given average value of 12950 K.

Xenon

Xe II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^5 \ ^2P^{\circ}_{3/2}$

Ionization energy: 20.975 eV = 169 175 cm⁻¹

For both experiments^{1,2} are used low pressure discharge lamps as a plasma source for Stark broadening measurements of Xe II spectral lines. The lamp is made of Pyrex glass with length 175 mm and 19 mm internal diameter. All other details about the experimental setup, plasma electron density diagnostics and electron temperature diagnostics one can find in the table Key data on experiments. Special attention is devoted to the check of line self-absorption. Only optically thin line halfwidths are used to derive Stark broadening parameters.

It should be noticed here that in Ref 1. are considered only multiplets with irregular behavior of Stark parameters, contrary to regular behavior, mentioned in Refs. 3 and 4. So, within Xe II multiplets M10, M12, M14 and M24 one can see discrepancies between Stark halfwidths, as well as, in Stark shifts inside of each mentioned multiplet. These are not disagreements caused by measurement error but they are caused by irregularities in perturbing levels positions.

In Ref. 2 are consider Stark broadening of Xe II low-intensity spectral lines only for which data can rarely be found or do not exist at all in the literature.

The experimental data for Stark halfwidths and shifts are compared with SC calculations performed in this work (TW).

In many cases the comparison is missing. Several semiclassical predictions for reported Xe II transitions are outside the $-0.6 \leq \Delta S/S \leq 0.1$ range of the completeness of a set of perturbing energy levels. This could be caused the set of atomic data calculated for the levels within the observed Xe II transitions for which the J_1K coupling of the angular momentum is valid. However, the $\Delta S/S$ value averaged over all reported Xe II transitions is similar to the corresponding one for the Xe III transitions, where the LS coupling dominate. This conclusion is supported by the B and C level of the atomic transition probability accuracies reported by ASD for the observed Xe II transitions. In the Numerical results table, the results for Xe II from Ref. 1 and 2 are presented.

CR (1984, 90, 02, 09).

References

- ¹R. J. Peláez, S. Djurović, M. Ćirišan, J. A. Aparicio, S. Mar, J. Phys. B: At. Mol. Opt. Phys. **42**, 125002 (2009).
- ²R. J. Peláez, M. Ćirišan, S. Djurović, J. A. Aparicio, S. Mar, Astron. Astrophys. **507**, 1697 (2009).
- ³W. Wiese, N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).
- ⁴W. Wiese, N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **47**, 185 (1992).

Finding list

Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.	Wavelengt h (Å)	No.
3101.51	42	3657.74	9	4244.41	7	4818.02	4
3104.40	23	3661.70	32	4269.84	10	4823.35	31
3112.74	23	3731.18	18	4321.82	10	4862.45	31
3145.02	25	3783.23	29	4373.78	33	4919.66	14
3148.99	22	3848.58	19	4384.93	2	4988.77	14
3165.27	11	3849.87	33	4406.88	41	4991.17	47
3272.91	24	3938.92	46	4448.13	40	5044.92	26
3281.26	34	3954.73	24	4532.49	20	5368.07	17
3313.48	28	4002.35	45	4651.94	12	5445.45	43
3327.46	3	4025.19	15	4674.56	4	5659.38	12
3373.92	27	4100.34	5	4693.34	37	5751.03	12
3386.30	35	4104.95	8	4715.18	39	5971.13	26
3461.26	30	4112.14	38	4773.19	36	6512.83	13
3564.30	3	4131.01	21	4775.76	44		
3612.37	6	4162.16	16	4779.18	1		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Low pressure discharge lamp filled with the continuously flowing helium as carrier gas with small addition of xenon (5%) at pressure of 3 kPa	Two wavelengths interferometry (5430 Å and 6328 Å)	Boltzmann plot of 24 Xe II spectral lines	Plasma observed axially end-on
2	Low pressure discharge lamp filled with the continuously flowing helium as carrier gas with small addition of xenon (5%) at pressure of 3 kPa	Two wavelengths interferometry (5430 Å and 6328 Å)	Boltzmann plot of 24 Xe II spectral lines	Plasma observed axially end-on

Numerical results for Xe II

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	$5p^6 - ({}^3P_2)6p$	${}^2S - {}^2[2]^o$	4779.18	22000	1			0.067	+/-	B ⁺	2
2	$5p^6 - ({}^3P_2)6p$	${}^2S - {}^2[1]^o$	4384.93	22000	1			0.072	2.79	B	2
3	$({}^3P_2)6s - ({}^3P_1)6p$	${}^2[2] - {}^2[2]^o$	3327.46	22000	1	0.221		- 0.032		B ⁺ , B	2
			3564.30	22000	1	0.269		- 0.040		B ⁺ , B ⁺	2
4	$({}^3P_2)5d - ({}^3P_2)6p$	${}^2[2] - {}^2[1]^o$	4674.56	22000	1	0.477		0.058		B ⁺ , B	2
			4818.02	22000	1			0.057			2

									C ⁺	
5	(³ P ₂)5 <i>d</i> - (³ P ₀)6 <i>p</i>	² [2] - ² [1] ^o	4100.34	22000	1		- 0.010			2
									C ⁺	
6	(³ P ₂)5 <i>d</i> - (³ P ₁)6 <i>p</i>	² [3] - ² [2] ^o	3612.37	22000	1		<i>d</i> < 0.01			2
7	(³ P ₂)5 <i>d</i> - (¹ D ₂)6 <i>p</i>	² [1] - ² [3] ^o	4244.41	22000	1		- 0.071	0.46		2
									C ⁺	
8	(³ P ₂)5 <i>d</i> - (¹ D ₂)6 <i>p</i>	² [1] - ² [1] ^o	4104.95	22000	1		- 0.009	0.06		2
									C ⁺	
9	(³ P ₂)5 <i>d</i> - (¹ D ₂)6 <i>p</i>	² [4] - ² [3] ^o	3657.74	22000	1		- 0.020	0.18		2
									C ⁺	
10	(³ P ₀)6 <i>s</i> - (³ P ₁)6 <i>p</i>	² [0] - ² [1] ^o	4269.84	22000	1	0.376	- 0.041		B ⁺ , B	1
				22000	1		- 0.054		B	2
			4321.82	22000	1	0.736	0.074		B ⁺ , C	1
11	(³ P ₀)6 <i>s</i> - (¹ D ₂)6 <i>p</i>	² [0] - ² [1] ^o	3165.27	22000	1		- 0.042	-/+		2
									C ⁺	
12	(³ P ₁)6 <i>s</i> - (³ P ₁)6 <i>p</i>	² [1] - ² [1] ^o	4651.94	22000	1	0.648	0.094		B ⁺ ,	1
			5659.38	22000	1	0.714	- 0.040		C ⁺	1
			5751.03	22000	1	1.077	0.231		B ⁺ , D	1
									B ⁺ ,	
									B ⁺	
13	(³ P ₁)5 <i>d</i> - (³ P ₁)6 <i>p</i>	² [1] - ² [2] ^o	6512.83	22000	1	0.984			B ⁺	2
14	(³ P ₁)5 <i>d</i> - (³ P ₁)6 <i>p</i>	² [1] - ² [1] ^o	4919.66	22000	1	0.553	- 0.044		B ⁺ , D	1
			4988.77	22000	1	0.828	0.156		B ⁺ ,	1
									B ⁺	
15	(³ P ₁)5 <i>d</i> - (¹ D ₂)6 <i>p</i>	² [1] - ² [1] ^o	4025.19	22000	1		0.039	0.36		2
									C ⁺	
16	(³ P ₁)5 <i>d</i> - (¹ D ₂)6 <i>p</i>	² [1] - ² [2] ^o	4162.16	22000	1		0.071	+/-		2
									B ⁺	
17	(³ P ₂)5 <i>d</i> - (³ P ₁)6 <i>p</i>	² [0] - ² [1] ^o	5368.07	22000	1	0.536			B	2
18	(³ P ₂)5 <i>d</i> - (¹ D ₂)6 <i>p</i>	² [0] - ² [1] ^o	3731.18	22000	1		<i>d</i> <			2

35	$(^3P_2)6p - (^3P_1)6d$	$^2[1]^o - ^2[2]$	3386.30	22000	1			0.285	0.32		2
										B ⁺	
36	$(^1D_2)5d - (^3P_2)4f$	$^2[3] - ^2[4]^o$	4773.19	22000	1	1.218				B	2
37	$(^3P_0)6p - (^3P_1)7s$	$^2[1]^o - ^2[1]$	4693.34	22000	1			0.532		B	2
38	$(^3P_0)6p - (^3P_1)6d$	$^2[1]^o - ^2[2]$	4112.14	22000	1	1.119	0.46			B	2
39	$(^3P_1)6p - (^3P_1)7s$	$^2[0]^o - ^2[1]$	4715.18	22000	1	1.853				C ⁺	2
40	$(^3P_1)6p - (^3P_1)6d$	$^2[2]^o - ^2[3]$	4448.13	22000	1	1.462				B ⁺	2
41	$(^3P_1)6p - (^3P_1)6d$	$^2[2]^o - ^2[2]$	4406.88	22000	1	1.391	0.50			B	2
42	$(^1D_2)5d - (^1D_2)4f$	$^2[1] - ^2[2]^o$	3101.51	22000	1	0.678	0.95			B	2
43	$(^3P_1)6p - (^3P_1)7s$	$^2[1]^o - ^2[1]$	5445.45	22000	1	1.228				B ⁺	2
44	$(^3P_1)6p - (^3P_1)6d$	$^2[1]^o - ^2[1]$	4775.76	22000	1			0.071	0.61		2
										C ⁺	
45	$(^1D_2)5d - (^3P_1)4f$	$^2[2] - ^2[4]^o$	4002.35	22000	1	1.681	1.19			B	2
46	$(^1D_2)5d - (^3P_1)4f$	$^2[2] - ^2[3]^o$	3938.92	22000	1	1.508	0.80			B	2
47	$(^1D_2)6p - (^1D_2)7s$	$^2[1]^o - ^2[2]$	4991.17	22000	1	1.866	1.72			C ⁺	2
The average ratio values							0.88		0.57		

Xenon

Xe III

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^4 \ ^3P_2$

Ionization energy: 31.05 eV = 250 400 cm⁻¹

The Pyrex glass discharge lamp used as a plasma source for determination of Stark broadening parameters of Xe III is identical to the lamps used for the same purpose for Xe II spectral lines, see reports for Xe II and the table of Key data on experiment for Xe III. The experiment, plasma diagnostics and details about self-absorption are identical.

Large number of transition arrays, which satisfies $-0.6 \leq \Delta S/S \leq 0.1$ range, enables comparison of, almost all, measured Stark broadening and shifts with the theoretical data. The only exception is multiplet M3, see the table of Numerical results for Xe III where only semiclassical results of this work (TW) are used in account.

CR (1990, 02, 09).

Reference

¹R. J. Peláez, M. Ćirišan, S. Djurović, J. A. Aparicio, S. Mar, *Astron. Astrophys.* **507**, 1697 (2009).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
3083.53	1	3539.94	10	3654.61	4	4657.78	6
3287.91	12	3607.02	2	3765.85	9	4673.67	5
3306.80	7	3609.46	2	3772.53	11		
3331.65	3	3632.14	9	3776.32	8		

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Low pressure discharge lamp with the continuous flow of helium as a carrier gas, together with 5% of xenon at the total pressure of 3 kPa	Two wavelengths interferometry (5430 Å and 6328 Å)	Boltzmann plot of 24 Xe II spectral lines	Plasma observed axially end-on

Numerical results for Xe III

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	d_m (Å)	d_m/d_{TW}	Acc.	Ref.
1	$(^2D^o)5d - (^2D^o)6p$	$^3F^o - ^3F$	3083.53	22000	1	0.15 4	0.86			B	1
2	$(^2D^o)6s - (^4S^o)4f$	$^3D^o - ^5F$	3607.02 3609.46	22000 22000	1 1	0.17 0 0.17 2	0.62 0.62			B B	1 1
3	$(^2P^o)5d - (^4S^o)4f$	$^1D^o - ^5F$	3331.65	22000	1	0.18 4				B ⁺	1
4	$(^2P^o)5d - (^2D^o)6p$	$^3P^o - ^3P$	3654.61	22000	1	0.21 2	0.74			B	1
5	$(^2D^o)6s - (^2D^o)6p$	$^1D^o - ^1F$	4673.67	22000	1	0.36 1	0.65			B	1
6	$(^2D^o)6s - (^2D^o)6p$	$^1D^o - ^1P$	4657.78	22000	1			- 0.022	0.09	C ⁺	1

7	$(^2D^o)5d - (^2P^o)6p$	$^3S^o - ^3P$	3306.80	22000	1			- 0.063	0.63		1
8	$(^2P^o)6s - (^2P^o)6p$	$^3P^o - ^3D$	3776.32	22000	1			- 0.035	0.28	C ⁺	1
9	$(^2P^o)6s - (^2P^o)6p$	$^3P^o - ^3P$	3632.14	22000	1	0.23	0.79	- 0.041	0.36	C ⁺ ,	1
			3765.85	22000	1	1	0.81			C ⁺	1
						0.23				B	
						9					
10	$(^2P^o)5d - (^2P^o)6p$	$^3D^o - ^3S$	3539.94	22000	1			- 0.022	0.19		1
11	$(^2P^o)6s - (^2P^o)6p$	$^1P^o - ^1P$	3772.53	22000	1	0.24	0.76	- 0.077	0.50	C ⁺	1
						5				B, C ⁺	1
12	$(^2D^o)6p - (^2D^o)6d$	$^3P - ^3P^o$	3287.91	22000	1	0.41	1.13			B	1
						1					
The average ratio values							0.78		0.34		

Zinc

Zn I

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 \ ^1S_0$

Ionization energy: 9.394197 eV = 75 769.31 cm⁻¹

Two experiments^{1, 2} with laser induced plasma are used for study of Stark broadening parameters of several Zn I lines. For the first experiment¹ Nd:YAG laser at 1064 nm is used to induce plasma in air from ZnO nanomaterial, while in second experiment² Nd:YAG laser at 266 nm is focused on various glasses to induce plasma with traces of zinc. The lasers, targets, details of plasma diagnostics, comments, and remarks for both experiments one can find in the table Kay data on experiments. Here we mention only that the electron temperature for Ref. 2, in the table of Numerical results, is derived using graphical presentation of plasma diagnostic results, see Fig. 7 in Ref 2.

The experimental Zn I halfwidths and shifts are compared with semiclassical results of this work (TW), see the table of Numerical results for Zn I lines.

CR (1976, 84)

References

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²C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet, M. Sentis, W. Viöl, Spectrochim. Acta B **101**, 32 (2014).

Finding list

Wavelengt		Wavelengt		Wavelengt		Wavelengt	
h	No.	h	No.	h	No.	h	No.
(Å)		(Å)		(Å)		(Å)	
4680.14	1	4722.16	1	4810.53	1	6362.35	2

Key data on experiments

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 1064 nm, 650 mJ, 5ns Target: ZnO nanomaterial in air	Halfwidth of the H α hydrogen spectral line	Multi-element Boltzmann plot	Plasma observed side on Abel inversion is not performed Self-absorption is not checked
2	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass located in the vacuum chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856 Å, 3863 Å spectral lines	Plasma observed end-on under angle of 15° with respect to the laser beam used for plasma generation Plasma divided in zones and calculated plasma parameters for each zone Self-absorption is checked

Numerical results for Zn I

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10 ¹⁷ cm ⁻³)	<i>w</i> _m (Å)	<i>w</i> _m / <i>w</i> _{TW}	<i>d</i> _m (Å)	<i>d</i> _m / <i>d</i> _{TW}	Acc.	Ref
1	4 <i>p</i> – 5 <i>s</i>	³ P ^o – ³ S	4680.14	11600	2.7	1.06	0.78	0.26	0.70	C	1
			4722.16	11600	2.7	1.37	0.99			C	1
				11200	1.0	0.41	0.82			C ⁺ ,	2
			4810.53	11600	2.7	1.25	0.87			C ⁺	1
2	4 <i>p</i> – 4 <i>d</i>	¹ P ^o – ¹ D	6362.35	11600	2.7	5.06	0.44		C	1	
									C		
									The average ratio values		

Zirconium

Zr II

Ground state: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^2 5s^4 F_{3/2}$

Ionization energy: 13.13 eV = 105 900 cm⁻¹

Nd:YAG laser is used to induce plasma for the study of Zr II 3391.98 Å spectral line.¹ Plasma is divided in zones and for each zone, plasma parameters are calculated to derive line profile. More details about experiment one can find in the table Kay data on experiment. The self-absorption check carried out. Similar technique as employed for Zr II Stark halfwidth measurement is used by the same group of authors for several other line shape studies, see reports for Ba I, Ba II and Ca II. Here, we mention only that the electron temperature for Ref. 1, given in the table of Numerical results, is obtained after analysis of graphical presentation of plasma diagnostic data, see Fig. 7 in Ref 1.

The comparison of experimental Zr II halfwidth with semiclassical calculation is performed with data of this work (TW), see the table of Numerical results for Zr II.

Reference

- ¹C. Gerhard, J. Hermann, L. Mercadier, L. Loewenthal, E. Axente, C. R. Luculescu, T. Sarnet,
M. Sentis, W. Viöl, Spectrochim. Acta B **101**, 32 (2014).

Ref	Plasma source	Method of measurement		Remarks
		Electron density	Temperature	
1	Nd:YAG laser at 266 nm Single pulse 300 mJ, 4 ns Target: fused silica, heavy flint glass and barite crown glass located in the vacuum chamber filled with argon at 5×10^4 Pa	Stark broadening of Si I 3905.5 Å spectral line	Intensity ratio of the Si I 3905.5 Å and doublet Si II 3856 Å, 3863 Å spectral lines	Plasma observed end-on under angle of 15° with respect to laser beam used for plasma generation Plasma divided in zones and plasma parameters and line shapes calculated for each zone

Key data on experiments

Numerical results for Zr II

No	Trans. array	Mult.	Wave. (Å)	Temp. (K)	Electron density (10^{17} cm^{-3})	w_m (Å)	w_m/w_{TW}	Acc.	Ref.
1	$(^3F)5s - (^3F)5p$	$a \ ^4F - z \ ^4G^\circ$	3391.98	11200	1	0.06	0.40	C ⁺	1